1973

The ecology of the mudminnow, Umbra limi, in Fish Lake (Anoka County, Minnesota)

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JONES, James Albert, 1916-
THE ECOLOGY OF THE MUDMINNOW, UMBRA LIMI,
IN FISH LAKE (ANOKA COUNTY, MINNESOTA).

Iowa State University, Ph.D., 1973
Zoology

The ecology of the mudminnow, *Umbra limi*,

in Fish Lake (Anoka County, Minnesota)

by

James Albert Jones

A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Department: Zoology and Entomology

Major: Zoology (Limnology)

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1973

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INTRODUCTION

Little is known of the ecology of the central mudminnow, Umbra limi (Kirtland). It resides in shallow water, in a variety of habitats, and over a wide geographical range. It has been observed and reported upon by many students of aquatic biology. The fact that it can thrive in habitats seemingly completely inhospitable to fish populations has elicited the greatest amount of comment. With one notable exception (Peckham and Dineen, 1957) references dealing with the ecology of the mudminnow are casual accounts of limited observations incidental to another study. There have been no ecological studies on the mudminnow in Minnesota.

Fish Lake is located about 35 miles north of Minneapolis-St. Paul in Anoka County, Minnesota. It lies within the Cedar Creek Natural History Area and is set aside for use in research and instruction in natural history. The only attempt at a comprehensive analysis of the lake was a survey by the Minnesota Division of Game and Fish, Section of Research and Planning, conducted in 1959. Conditions have changed considerably since the survey as a result of physiographic alterations induced by man.

I collected data for this study during the periods August 4 to November 8, 1967; January, 1968; March 31 to September 15, 1968; January, 1969; February and March, 1971; and July and August, 1971. Observations were made in January, February, March, and April when the lake was covered with ice and in all months when the lake was free of ice. I made 131 trips to the lake for recording data; many trips in preliminary observations were not recorded. A minimum of 3600 trap-days were used in taking 3036 mudminnows each yielding at least one piece of datum; many mudminnows were captured, examined casually and released. Data on the habitats and other organisms were collected at this same time.

OBJECTIVES

My objectives in this study were to investigate the mudminnow, <u>Umbra limi</u>, in Fish Lake and the associated marshes. This involved the consideration of the conditions presented by the environment and the response of the mudminnow to these conditions; consideration of the population of mudminnows and certain phenomena which are characteristic of populations; and consideration of the individual mudminnows and certain characteristics which pertain more to individuals.

Environmental considerations included the physical, chemical, and biological factors which were observed to be of immediate importance, or which, due to their abundance and proximity, were thought to be of potential importance, to the mudminnow. Included were the factors of water level, temperature, oxygen, vegetation, insects, mollusks, plankton, and fish of other species.

The population was analyzed and compared with other populations of mudminnows reported in the literature as regards its age structure, the size range of the fish by age and by sex, the number of eggs produced per female, and the time and place of spawning. Other considerations of population phenomena included seasonal distribution, migration related to reproduction, and migration related to the colonization of a "new" habitat. Food and feeding habits and parasites were given some attention.

Objectives related to individuals included establishing techniques of capturing and holding the mudminnows, determining the effect of preservation on their length and weight, and establishing a technique of aging them.

THE MUDMINNOW

Information dealing with the mudminnow is widely dispersed in the literature. Certain literature pertinent to the present study is reviewed here.

Classification

A partial classification of the mudminnow which was pertinent to the survey of the literature is as follows (preferred name first):

class Osteichthyes,
  subclass Actinopterygii (Neopterygii),
    superorder Teleostei (Isospondyli),
      order Clupeiformes (Haplomi),
        suborder Esocoidei,
          family Umbridae,
            genus *Umbra*,
              species *Umbra limi* (Kirtland, 1840),
              common name **central mudminnow**

Synonomy and confusion exist in the literature. The species was first described as *Hydrargira limi* by Kirtland (1840) from specimens collected at the headwaters of Yellow Creek in Ohio. Abbott (1871, 1874) referred to the species as *Melanura limi*. The species was confused with *Umbra pygmaea* which was discussed as *Fundula cyprinodonta* Cuvier by Carbonnier (1874). Gill (1906) pointed out that *Fundula cyprinodonta* was a species of *Umbra*.

By common name it has been referred to as "young dogfish" and as the barred mudminnow and western mudminnow as well as the central mudminnow.

Three species of fish comprise the genus Umbra. Umbra krameri is found in bogs and brooks along the Danube in Europe; Umbra pygmaea is found in the eastern United States; and Umbra limi is more widespread in the central and eastern United States. The family Umbridae includes two other genera each containing a single species: Novumbra hubbsi (Olympic mudminnow) and Dallia pectoralis (Alaskan black fish). Both are fish of small size and have the reputation for great tolerance of the adverse conditions in their environments.

Characteristics

The following compilation of characteristics describing the central mudminnow is from several sources. (Characteristics commonly used in keys are underlined.)

Snout short. Mouth small. Teeth feeble and all similar and equally developed. Body moderately elongate and covered by cycloid scales without radii. Transverse series of scales 33-35. No lateral line. Head scaled laterally and dorsally.

Dorsal fin, 12-13 rays, set far back overlapping anal. Ventral fins, 6-7 rays, slightly in front of dorsal. Pectoral fins, 11-14 rays, broad and rounded and inserted low on the body. Anal fin, 5-6 rays, rounded. Caudal fin, rounded, homocercal.

Branchiostegals 6-9. Mandibular joint located before the posterior margin of the eye. Vertebrae, 35, elongate. Scapula, coracoid and pectoral ossified. Postcleithrum and inframandibulars present. Nasals and supramaxillary (premaxillary) absent.

The color of the mudminnow is quite constant with the light brown background mottled with darker brown forming no particular pattern. There is, uniformly, a conspicuous black vertical bar across the peduncle just before the caudal fin.

Secondary sex differences include: the larger size of the females, the shorter and thicker caudal peduncle and slightly coarser scalation in the breeding males, the longer anal fin in the males, and an iridescent purplish coloration on the anal and pectoral fins in the larger males in some populations.

Distribution

Forbes (1909) summarized the known distribution of the mudminnow as being the following drainages: the Great Lakes basin, Quebec and New England, the North Atlantic, the Lower Mississippi and Ohio, and the Upper Mississippi and Missouri. He noted that it has not been reported from the following: the Hudson River, the South Atlantic, the Florida Peninsula, the East Gulf, the West Gulf and the Rio Grande, the Far Northwest and the Far North. No references encountered in this study extend or contradict his generalization nor was any effort directed toward verifying it.

Habitat

The habitats involved in this study will be described in detail later under the discussion of Fish Lake and its associated marshes. The characteristics of them fall well within the great variety of habitats described for the mudminnow in the literature. Abbott (1871) described it as a mudloving fish. Adams and Hankinson (1928), in studying Oneida Lake, found it only in those parts of the lake less than 6 feet in depth. They further generalized that it was a little-known fish of sluggish creeks, sloughs, and marshes with much vegetation and mud bottoms. Here they proposed it moved about, found safety, and hibernated. Bean (1892) noted that it had been plowed up in ponds and swamps which had dried out. Peckham and Dineen (1957) studied the mudminnow in Judy Creek near South Bend, Indiana. They found it absent in the stream where the bottom was rockstrewn with very little vegetation and scarce at the headwaters of the stream where the depth of the water was less than one foot. They found it in dense vegetation along the margins of the stream and in midstream where aquatic vegetation was dense.

Migration

Several observations have been made on the change of habitat and migration of the mudminnow. Peckham and Dineen (1957) found its migration in Judy Creek restricted to lateral movements into the flooded shore areas during periods of spring flooding and heavy rains. They found that it avoided strong currents, never being found in parts of the stream with swift current. Adams and Hankinson (1928) noted marked migratory movements to streams for breeding. They cited observations by Hankinson (Jr. author) of upstream migration, and of Gill (1904) of its migration up clear rapid streams. They reported that when water is receding in its habitat the mudminnow is capable of jumping from one pool to another.

Food

Cahn (1927) concluded that the food of the mudminnow was largely aquatic plant material including duckweed (*Lemna*), particles of *Elodea*, *Ceratophyllum*, and other plant material, together with any minute animal life that was attached to this growth. He explained particles of *Hydra* sp. in the intestine as probably having been ingested with Elodea. Forbes (1883) examined 10 specimens and found 40% vegetable matter, chiefly Wolffia and some algae. He also found mollusks, insects, entomostracans, and amphipods. Pearse (1918) examined 50 specimens finding Chironomus, Tanypus, a caddisfly, lepidopterous larvae, midges, Hemiptera, mites, entomostracans, mollusks, and plant material including seeds and filamentous algae. Abbot (1874) concluded that it is carnivorous.

Peckham and Dineen (1957) examined stomachs of 702 mudminnows from Judy Creek (Indiana) and other habitats. They concluded that in Judy Creek the central mudminnow is a carnivorous bottom feeder. Chironomids, copepods, ostracods and cladocerans were the principal food items of the young-of-the-year. Small crustaceans were less important to the adults. In addition to chironomids the chief food items were mayflies, caddisflies, and mollusks. A few fish were eaten by the mudminnow. Plant material appeared to be accidental in the diet. Odonata naiads, though present in the habitat, were very infrequent items in the diet.

Tolerance of Adverse Conditions

References in the literature to Umbra limi, Umbra spp., Novumbra and Dallia rarely fail to comment on some aspect of the exceptional tolerance of these fish to the adverse conditions in the habitats which they frequent, e.g., Abbott (1871), Adams and Hankinson (1928), and Bean (1892).

Scholander et al. (1953) showed in experiments on Dallia pectoralis that it could not survive total freezing. Borodin (1934) tested nine species of fish including Umbra limi. He concluded that all fish, when frozen in water so as to be encased in a cake of ice, died.

The mudminnow is physostomous and capable of breathing air at the surface of the water (Brimley, 1896; Carter, 1957; Rauther, 1914).

Parasites

Hoffman (1967) reviewed the literature on parasites of North American fish. For the mudminnow he listed 3 protozoans, 14 trematodes (8 of which are larval forms), 1 cestode (larval form), 3 nematodes (1 a larval form), 4 acanthocephalans, and 1 crustacean.

Breeding Habits

Breeding habits of the mudminnow were referred to several times in the literature. Adams and Hankinson (1928) generalized that it breeds in brooks, ponds, forested swamps, open swamps or marshes. They stated that it ran upstream to spawn and laid eggs attached to vegetation in ponds. Peckham and Dineen (1957) collected prolarvae in flooded backwaters of Judy Creek. They concluded that the flooded areas provided excellent breeding grounds and protected habitats for the young.

Breeding takes place in March and April (Abbott, 1874; Adams and Hankinson, 1928; Everman and Clark, 1920; Forbes and Richardson, 1907; Wright and Allen, 1913). Peckham and Dineen (1957) referred to the spring spawning runs and the time of egg deposition. However, Ryder (1886) apparently came the nearest to actually observing egg deposition and early development. He noted that eggs measured 1.6 mm in diameter and were laid singly upon aquatic plants. The young hatched on the sixth day at which time they were 5 mm long.

Age and Growth

Scales, length frequency, and otoliths have been used in the effort to determine the age of the mudminnow. Van Oosten (1941) in discussing scales in relation to aging fish pointed out that in the mudminnow the circuli (striae) were not laid down in concentric rings but rather were of a linear nature paralleling the sides of the scale. No annuli were apparent.

Applegate (1943) used length frequency. He found that two modes, corresponding to age-groups 0 and I, were easily distinguished but that overlap in fish of greater length was too great to detect individual age groups. This overlap was attributed to slow growth and the tendency for decreasing growth rate with increasing age, an extended breeding season, lack of uniformity of growth, and changing environmental conditions from one season to the next, or any combination of the above factors.

Peckham and Dineen (1957) noted that their fish were preserved in alcohol to enable them to examine the otoliths for the purpose of aging. In their published report they did not include information on aging. However, Peckham (1955) reviewed the literature on the use of the otoliths to determine age in fishes and described the technique which he used in studying the otoliths in the mudminnow.

Carlander (1969) tabulated age and size data on the mudminnow from three sources: Applegate (1943, Michigan), Peckham (1955, Indiana), and Westman (1941, New York).

Reproductive Potential

Carlander (1969) included three reports dealing with reproductive potential in the mudminnow as follows: Everman and Clark (1920, Indiana), Peckham (1955, Indiana), and Westman (1941, New York). Combined in chart form, 11 size ranges of fish with the mean and range in egg number for each size range were presented. In addition a single range in egg number per female was given.

Westman (1941, New York) and Applegate (1943, Michigan) found that male and some female mudminnows matured at age I.

Length and Weight Changes Resulting from Preservation

Investigators have previously established that length and weight of fish are altered when preserved in formalin, when preserved in alcohol, and in rigor mortis at death in no preservative. Sigler (1949) reported 5.6% increase in weight and 1.2% decrease in length when preserved in formalin. Parker (1963) included a review of the literature on the subject. While variations occurred in percentage of change there was general agreement that condition factor (W/L^3) increased as a result of death alone and as a result of preservation in formalin and/or alcohol.

Parker investigated the relationship between length and weight changes and time in storage as well as type of preservative. He found that most of the length change took place within 12 hours and that substantially no change took place after 30-40 days. He found that the fish in freshwater formalin gained weight rapidly for 1 or 2 days then lost weight at a decelerating rate to the time of last measurement (225 days).

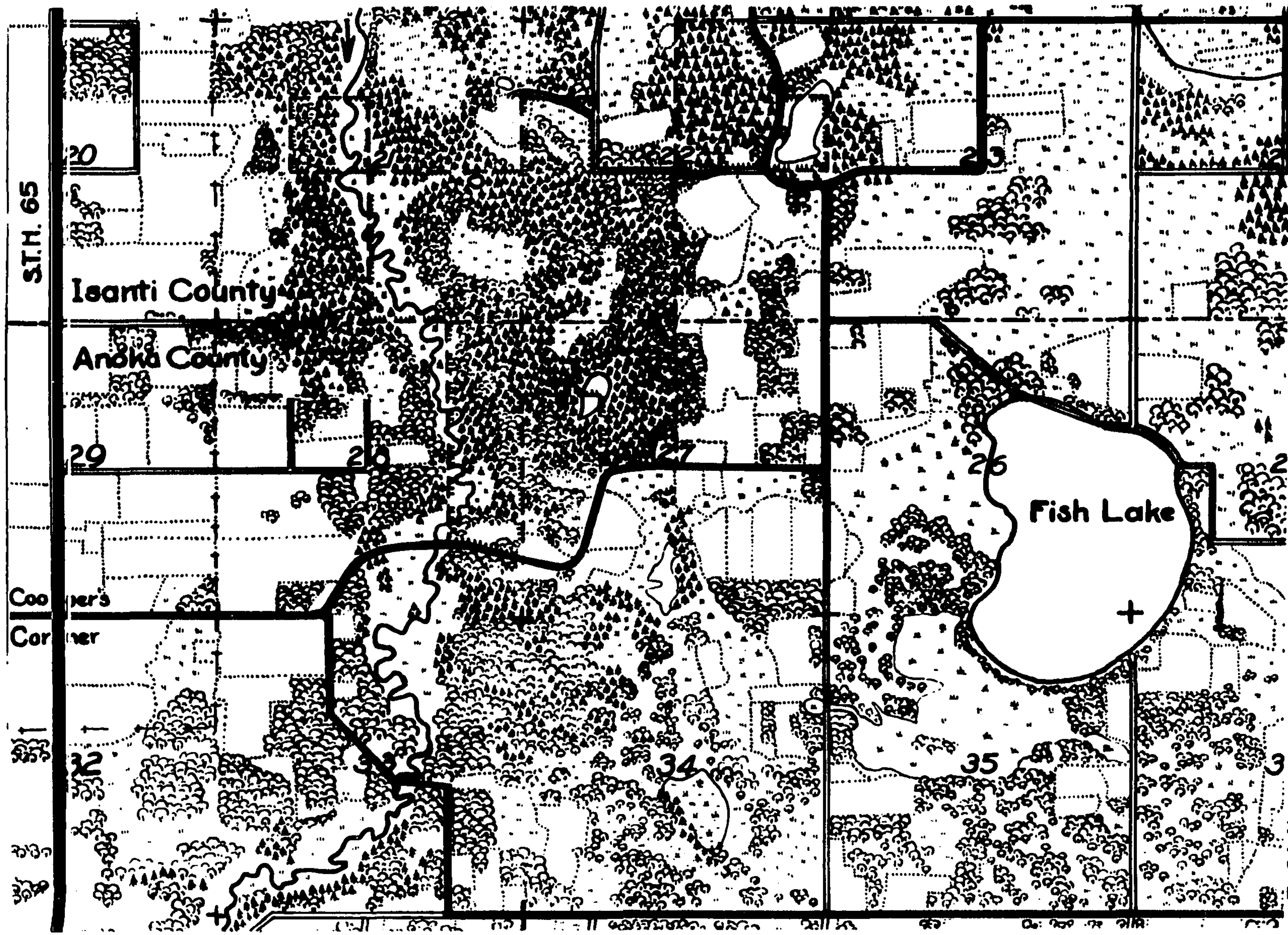
THE STUDY AREA

Fish Lake is located in Anoka County, about 35 miles north of St. Paul, near Bethel, Minnesota. It lies within the Cedar Creek Natural History Area which is owned and managed jointly by the Minnesota Academy of Science and the University of Minnesota (Figure 1). The lake has received no insecticide treatments, weed control treatments, or artificial fertilization. There is no swimming or fishing in the lake.

Three marshes are intimately associated with the lake (Figure 2). To the west, West Marsh or Alvar's Marsh is broadly connected to the lake; to the east, East Marsh is separated from the lake except for a narrow channel through which water flows into the lake from the marsh when the water is high; to the south, South Marsh connects to the lake by a narrow channel which maintains a continuous flow into the lake except during periods of prolonged drought and during the winter when the marsh is frozen.

The total watershed affects the quality of the lake and the marshes and the biota therein. It lies within an area of level to gently rolling terrain of predominantly sandy loan soils. The sand was initially deposited as outwash from the Grantsburg Sublobe of the Des Moines Lobe of the Wisconsin Glacier. The area is not well drained. The water table is high with many small, shallow, marshy depressions. Larger water areas such as Fish Lake are believed to be irregularities lying in old deserted river channels of the Mississippi River as it flowed around the Grantsburg Sub-lobe. The vegetation cover of the watershed is largely of oak and birch with a scattering of coniferous trees. The small tracts of wetland take two forms. Some are cattail marshes while others are classical alder

Figure 1. Cedar Creek Natural History Area. (Photo from a map prepared by the University of Minnesota, Minneapolis, Minn.)



S.T.H. 65
Isanti County
Anoka County
20
29
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26
Fish Lake
34
35
T. 34 N.

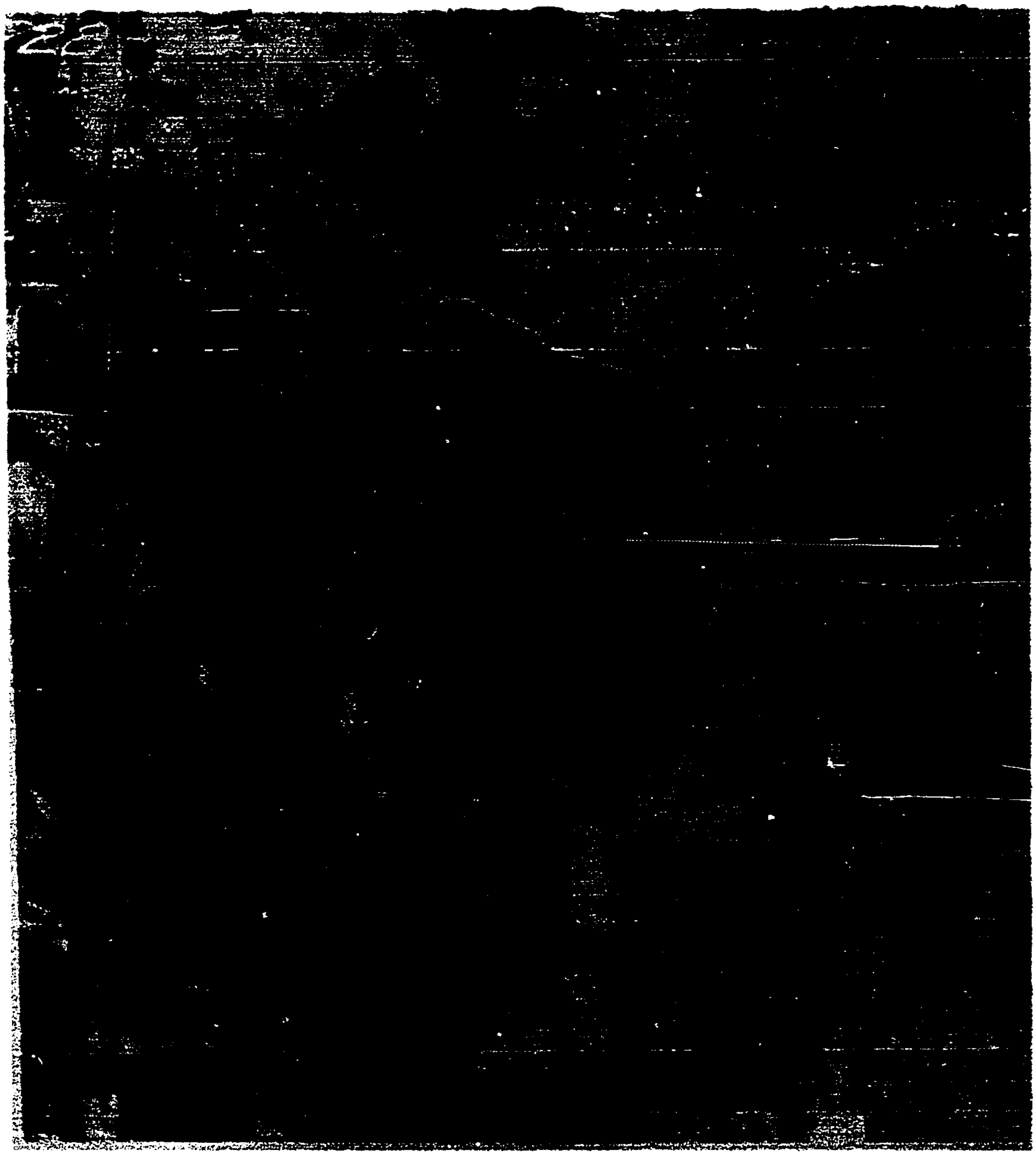


Figure 2. Aerial photo (BIM-3-13, USDA, October 10, 1938) of Fish Lake. East, South, and West Marshes are included in the photo.

and tamarack or cedar bogs. Historically much of the upland was in agriculture but at the present time most of it is being idled.

The findings from a survey of Fish Lake by the Minnesota Conservation Department, Division of Fisheries, are included in the "RESULTS" section and compared to conditions found in this study.

METHODS AND MATERIALS

Trapping and Collecting Mudminnows

Trapping proved to be the most successful method of capturing mudminnows. I used conventional double-cone minnow traps, 17 inches long, 8 inches in diameter in the middle, and 6 inches in diameter at the ends with a 1-inch-diameter hole at each end. They were of ¼-inch plastic mesh construction. When new the traps were white but as they were used they became stained to shades of brown. Being lighter than water they could be floated or by weighting them they could be sunk. These traps were used in the lake and in the marshes and channels.

The same traps were used under the ice. Holes about 1 foot in diameter were opened in the ice by means of an ice chisel. To maneuver a trap through the hole and position it I found it necessary to attach two lines to the trap. One line, attached to the end of the trap, let the trap down through the hole; the second, attached at the middle of the trap, oriented the trap with its long axis parallel to the bottom.

No bait was used in the traps. I discovered in preliminary sampling that unbaited traps caught as many fish as traps baited with bread or banana peal.

In an effort to better sample the smaller young-of-the-year mudminnows, which I found were able to pass through the ¼-inch mesh of the regular traps, I used window screen to construct a trap 12 inches high, 12 inches wide, and 18 inches long. It was used in the channel leading from South Marsh. This trap gave limited success. The pores of the screen were not large enough to allow filamentous algae and plant fragments being carried in the water to pass through resulting in the reduction of the flow of water through the trap. Since the mudminnows, on their downstream migration, are very sensitive to current and stay in the fastest flowing water very few were captured in this trap.

I also constructed six small, double-cone traps of window screen and placed them in the marsh in an attempt to collect crawling and swimming insects and young fish in the small channels between the hummocks. These traps did not work.

I used two types of dip nets to collect in the channels between the hummocks. A heavy-duty insect net with a nylon bag was used by gripping the end of the bag in the same hand with the handle. Using the net in this manner kept the material dipped from the bottom near the aperture of the net for sorting, washing, and observing for fish. A bronze screen between two wooden handles was used on a few occasions but was not durable enough. Collecting by dip nets was very inefficient. The disturbed mudminnows dove into the bottom debris. This made it necessary to scoop up a netful of the "bottom" and search through it for mudminnows. Several dips were required for each mudminnow captured.

Seining did not work. In the lake where the vegetation was sparse enough to allow the pulling of the seine there were no mudminnows. In vegetation the net would roll up and catch no fish.

Electric shocking and chemical treatment were not used. It has been well established that neither method is effective in habitats with high organic content and dense vegetation. Especially is this true when the fish have a strong affinity for the bottom. The methods used caused the least possible disturbance in the habitat and hopefully did not greatly alter the natural behavior of the mudminnows. I felt that under normal conditions the mudminnows were susceptible to capture by minnow traps and that fish taken constituted a representative sample of the population.

Direct Observation

The habitat and the behavioral traits of the mudminnow made them difficult to observe directly. They were very wary and seclusive. The disturbance caused by my approaching a proposed observation site sent them into cover. Rarely I had a fleeting glimpse of a swirl at the surface, in the bottom muck, or into the vegetation but more frequently nothing, this in spite of the fact that continuous trapping in the area gave assurance that mudminnows were present. (Brook sticklebacks and fathead minnows could be observed readily.)

I was able to observe the mudminnows as they moved through the channels during migration. Even here the movement, especially of the older fish, was by darting from one shadow or shelter to another.

Observation of the mudminnows in captivity gave a good clue to the reason for the difficulty in observing them in nature. In the aquarium with no cover or substrate in which to hide they remained motionless in place for very long periods. When startled they took wild darting action striking the bottom, the sides and jumping from the water. After the dashes they came to rest and froze, frequently with the trunk twisted at a slight angle, and with the pectoral fins twitching nervously but very slightly.

Plankton Analysis

I used a plankton net 12 inches in diameter constructed of #20 bolting silk (125 meshes to the inch) to take plankton samples on each visit to the lake. When the lake was covered by ice the sample was taken through a hole in the ice by weighting the bottom of the plankton net, lowering it into the hole about 2 feet then raising it to allow the water to drain through. The operation was repeated five times to constitute a sample. Lowering the net just 2 feet kept it above the vegetation and did not stir up the bottom. The sample was concentrated in the collecting vial of 35-ml capacity. The vial was emptied into the sample bottle and the net rinsed down a second time into the vial giving a sample of 70 ml. Two ml of 40% formalin were added to preserve the organisms. In the laboratory the sample was brought up to 100 ml for quantitative analysis. A sample of living material was generally taken to the laboratory to facilitate identification.

In summer, I took samples by making a 10-foot tow beside the boat. It was convenient to wash the net into the single 35-ml sample. The sample was preserved with formalin and again diluted to 100 ml for analysis.

I used a Sedgewick-Rafter counting chamber for counting. The sample was thoroughly mixed and 1 ml placed in the chamber to be examined first under a stereoscopic microscope (magnification 10-30X) to make a total count of copepods and cladocerans, then under the low power (100X) compound microscope to make a total count of smaller organisms. Two slides were examined from each sample collected and the counts averaged.

Food Analysis

Stomachs from several mudminnows were examined and the contents noted. In January I took the fish from the minnow traps directly into the laboratory and examined them immediately. In April the fish were killed in 4% formalin in the field then examined later in the laboratory. Each stomach was removed by severing the anterior end at the esophagus and the posterior end at the narrowing to the intestine. Each was split lengthwise and the contents washed into a petri dish for examination under a stereoscopic microscope. Contents were examined qualitatively only.

Oxygen Determination

In the winter, oxygen determination was made by the modified Winkler method using samples taken through the ice with the Kemmerer water bottle. Care was taken not to stir air into the water in the ice hole. I found it necessary to fill the sample bottles and add the chemicals with the bottles submerged, up to the neck, under water to prevent their freezing and breaking. The bottles were then carried in an inside pocket. Titration was performed in the laboratory within a couple of hours of the time of taking the sample. When the lake was free of ice the YSI oxygen-temperature meter (Yellow Springs Instrument Company, Yellow Springs, Ohio) was used.

Temperature Determination

To make temperature determinations in shallow water I used either the Taylor maximum-minimum thermometer or a standard laboratory thermometer; in deeper water or when a series of temperatures at different depths were taken I used the YSI oxygen-temperature meter.

Testing Toxicity of Water and Tolerance of Freezing

Holding cages were constructed for two different tests in the field work. To test the toxicity of the water under the ice and the viability of mudminnows at different depths in the water and in the ice, I constructed a cylindrical cage 40 inches high and 12 inches in diameter, with dividers across at 10-inch intervals. Each compartment was furnished with a small gate to allow the introduction of the fish. Mudminnows, captured in traps in the lake, were transported directly to the holding cage, introduced into the cage at the water level and submerged immediately. I am satisfied that the capture and handling of the mudminnows had no adverse short-term effect on them. Many were similarly handled for transport to the laboratory where they were kept alive in aquaria for several days.

I built the second type of holding cage to test winter survival in the marsh. One-quarter-inch wire screen was used to form a cage 3 feet square with the top and bottom open. A cover of the same material was provided to prevent predation from the top and to prevent the escape of the mudminnows in case the water rose over the top of the cage. Four of these cages were installed in South Marsh. Using care to avoid standing inside the plot I used a tiling spade to dig a channel around the plot. Digging among sedge roots and peat, the forming of the channel was very difficult. It was impossible to get a bottom seal under the wire. Twenty-five mudminnows, captured in the marsh, were introduced into each cage. I hoped that a few would remain in the cage to be found during the winter and in the spring. The contents of two cages were removed in January to see at what level the mudminnows were spending the winter and two were livetrapped in the spring to determine survival and to determine the time of beginning activity. Near one of the cages I placed six temperature probes at 6-inch intervals from 18 inches below to 12 inches above the water surface. They were connected into a jack-box into which the meter could be plugged for reading.

Parasites

Following the procedure suggested by Hoffman (1967) I examined living and freshly killed mudminnows for parasitic infection. While they were still alive, and in the lake water, I examined them under the dissecting microscope for external parasites. Next I examined, in order, the gills, coelom, swim bladder, digestive tract, cloaca, and the meninges and cavities of the brain. Metacercariae embedded in the skin were removed as the final step.

Preserved mudminnows were examined for metacercariae only.

Breeding Habits

The study of the breeding habits of the mudminnow in Fish Lake was pursued throughout the spring and summer of 1968. By direct observation and by sampling with minnow traps and dip nets I followed the mudminnows through their migration to the breeding grounds, spawning, and migration back into the lake following spawning. I also sampled the young through the early growing period. Frequent sampling during the breeding period established the place and time of breeding, the age and size of breeding fish, the reproductive potential, the approximate time for development from egg to young, and the conditions of the breeding area. Attempts were made to observe the actual spawning process. Comparison was made between the patterns in Fish Lake and those in reports from other areas.

Age and Growth

The otoliths proved to be very satisfactory for the determination of age in the mudminnow. Extensive collecting through the ice during February, March and April of 1971 produced mudminnows for analysis. I examined these specimens fresh and after preservation in alcohol. With the knowledge and experience thus gained I turned to mudminnows from previous collections preserved in formalin and found that otoliths from them could be read with the same high degree of confidence as those which were fresh or preserved in alcohol.

The sacculith, the largest of the otoliths, was removed from each side then both were stored and examined in glycerin. I found they could best be observed against a dark background using lateral lighting and about 10X magnification.

I tried a variety of techniques in the attempt to use the scales for aging including examination in water, xylol, alcohol, and glycerin. I used eosin and carmine stains in the attempt to show a difference between winter and summer growth.

Length frequency distribution was examined carefully. During periods of migration I was able to collect a large number of mudminnows over a very short period of time. Three periods yielded collections for length frequency analysis: the spring spawning run, a mid-summer colonization run, and the late-summer migration of young-of-the-year to the lake. Each period represented a different segment of the population. In addition the young-of-the-year were examined at several stages of development.

Reproductive Potential

The data on reproductive potential are based on 91, 2-year-old; 22, 3-year-old; and 3, 4-year-old female mudminnows. Ages were determined by analysis of the otoliths. Egg counts were made by extracting the left ovary, freeing and counting each egg and multiplying by two. I made counts of both the left and the right ovaries on six fish to determine if they were the same. Counts on the six fish gave the following values for the left and right ovaries respectively: 731, 738; 567, 488; 342, 397; 454, 501; 803, 760; and 1518, 1473.

Chi-square distribution values were calculated for each fish, for the total sample, and for pooled chi-square. No values of chi-square were significant at the 5% level. I concluded that counting the eggs of a single ovary, the left, and multiplying by 2 for total eggs was a satisfactory procedure for the purposes of this study.

Length and Weight Changes Resulting from Preservation

I extended the field work into the summer of 1971 to collect mudminnows for length-weight analysis. The fish were taken from Fish Lake using the same trapping method used previously. They were transported alive to the laboratory, weighed and measured promptly, then preserved in 4% formalin. Length was determined to the nearest millimeter and weight to the nearest 0.01 gram. Total length from the tip of the snout to the longest rays of the caudal fin was used. For weighing, each fish was blotted in paper toweling until no wet blot appeared on the towel.

The trapping period extended over 6 weeks. The last fish in the series was placed into preservative on August 17, 1971. All fish were measured and weighed, after preservation, on October 1, 1971, and again on October 29, 1971.

Plants

Analysis of the plants of Fish Lake included identification of the various species, noting their distribution in the lake, and in most cases noting the time of their first appearance, flowering, setting seeds, and disappearance. Distribution and development were noted during the many crossings of the lake during trapping operations. In addition, I ran transects on the north-south axis across the lake in approximately parallel lines plotting in conspicuous formations. Special relationships between plants and various animals were noted.

Plants were collected in various stages of development. Most identification was done with fresh material. Samples of all plants identified were pressed and dried. Voucher specimens of plants are deposited at the University of Minnesota Herbarium.

Insects

The insects considered in this study are those that were especially conspicuous by their size and/or their abundance. Many of them were taken in the minnow traps while collecting mudminnows. Others were captured by netting. Except for examples taken for identification, those collected in water were preserved in formalin along with the mudminnows. Others were pinned and dried. Voucher specimens of insects are deposited in the University of Minnesota insect collection.

RESULTS

Seasonal Distribution and Migration Patterns

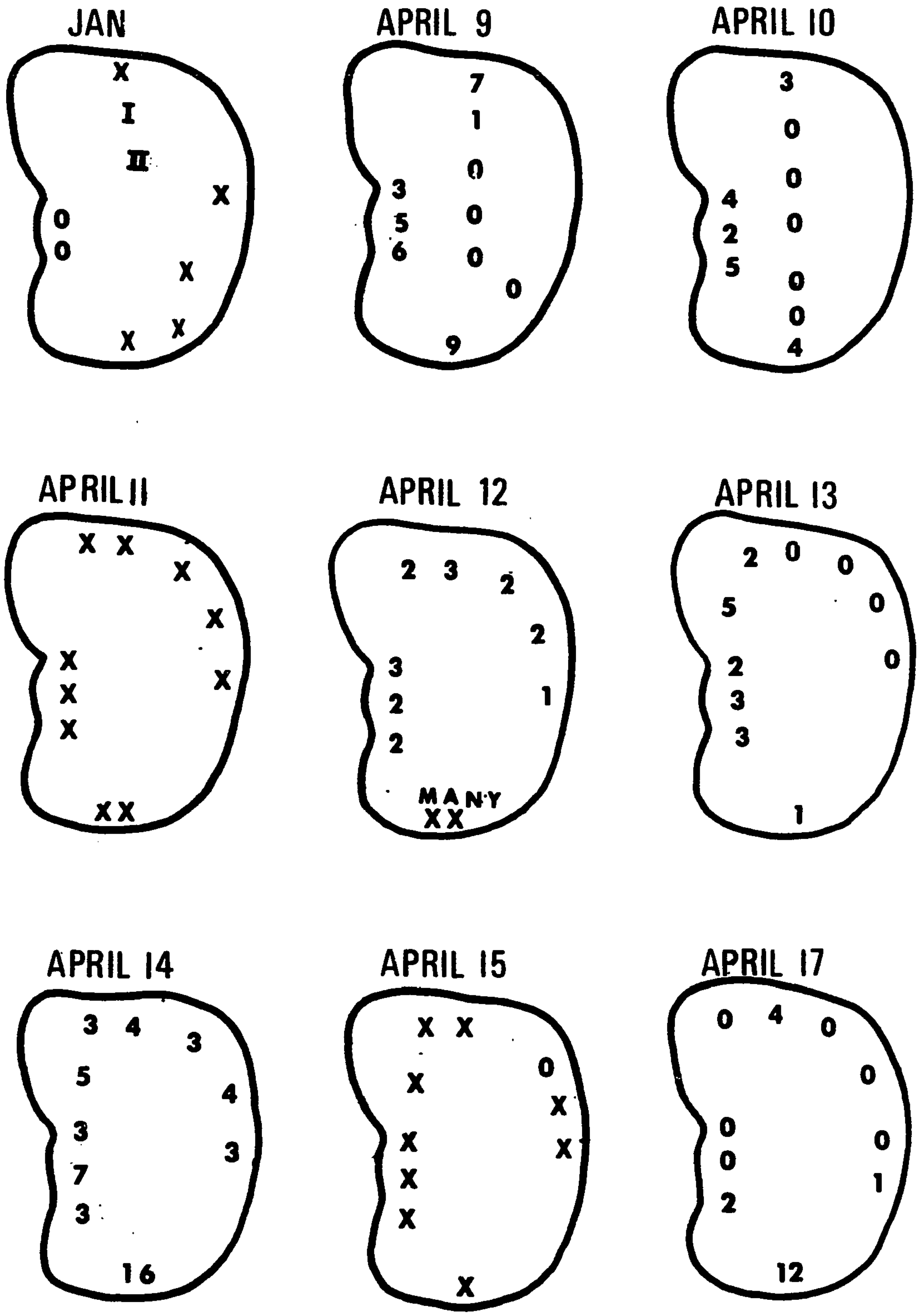
Five major population shifts were noted: movement within the lake from a general homogeneous lakewide distribution to the shore area then peripherally to the marsh openings, migration of adult breeders into the marshes, return of the adult breeders to the lake, movement of the young-of-the-year from the marshes to the lake, and colonization of a "new" habitat.

Winter distribution

Between January 5 and January 27, 1968, I attempted to conduct widespread sampling under the ice in Fish Lake and the adjacent marshes. No mudminnows were taken from the marshes. East and South marshes were frozen into the bottom. West Marsh was also frozen into the bottom except along the narrow band bordering the lake proper. The water below the ice in this band produced no mudminnows. It is believed that conditions here were toxic and uninhabitable. A strong odor came from the openings. Twenty-four mudminnows collected in the lake and placed in holding cages in this water succumbed within 24 hours. While no chemical tests were made of this water, it is felt that a lethal factor other than low oxygen level was involved. The oxygen level in the lake proper dropped to nearly 0 ppm in mid-January and remained so until mid-March yet the mudminnow population survived well.

In Fish Lake itself, mudminnows were taken at all trapping sites except along the west margin (Figure 3, Jan.). Sets were made in as little as 1 foot of water below the ice and in as much as 4 feet of water below

Figure 3. Series of diagrams showing the location of trapping sites in Fish Lake in January and from April 9 to May 12, 1968. Arabic numerals indicate the number of mudminnows captured at that site during the time interval since the preceding date. X indicates captures without the number of fish being noted. Roman numerals I and II indicate the sites of two stations sampled repeatedly during January, 1968. (On two pages.)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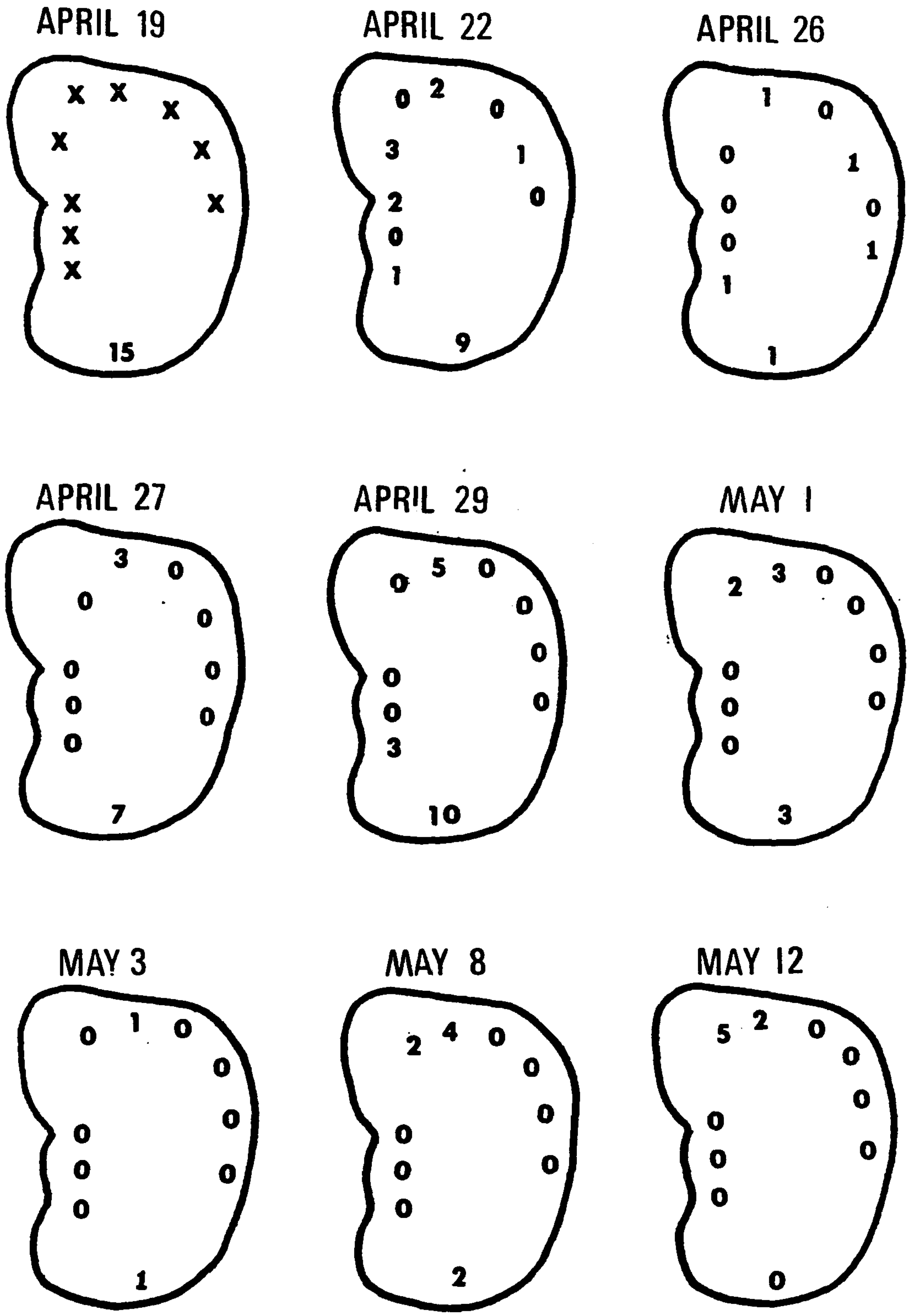
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MAY 3
0 1 0 0 0 0 0 0 0
1
MAY 8
2 4 0 0 0 0 0 0 0
2
MAY 12
5 2 0 0 0 0 0 0 0
0

the ice, over mud bottom and over sand bottom, in and over vegetation and over areas free of vegetation, and with the trap suspended just below the ice and with the trap on the bottom.

Stations I and II were trapped several times between January 10 and January 25, 1968. Records were kept on the three species of fish taken in the traps (Table 1). Umbra limi was taken with regularity during the trapping period.

Due to failure of the plastic fastener holding the two halves of the traps together it was possible for the traps to come open. Four trap-days were lost because of this failure. They are designated "No Data" in the table. Special care was needed to insure that the traps were oriented with their long axis parallel to the lake bottom. On the day of "0" capture, Station II, January 24, 1968, the trap was oriented standing on one end on the bottom.

The results of this sampling gave two important pieces of information. The mudminnows in Fish Lake are widely distributed in the lake during the winter; the mudminnows remain active, moving about and feeding, and do not hibernate during the winter as once proposed (Adams and Hankinson, 1928). (The contents of the stomachs of these fish are reviewed in the section on "Food and Feeding.")

Results of exploratory trapping in June and July, 1967

In June and early July, 1967, I conducted exploratory trapping in Fish Lake. All traps were set out in the lake some distance from the shore. Repeated sets across the lake produced no mudminnows. During this period I became very concerned regarding the status of the mudminnow

Table 1. Number of each of three species of fish captured in a single minnow trap over 24-hour periods at each of two stations. Trapping was conducted under the ice in Fish Lake in January, 1968.

Date	*Eucalia inconstans* Station I	*Eucalia inconstans* Station II	*Pimephales promelas* Station I	*Pimephales promelas* Station II	*Umbra limi* Station I	*Umbra limi* Station II
	I	II	I	II	I	II
Jan. 10	0	No data	1	No data	16	No data
Jan. 11	No data	3	No data	2	No data	11
Jan. 16	15	No data	15	No data	16	No data
Jan. 17	12	31	10	22	11	11
Jan. 18	11	28	12	14	9	12
Jan. 23	9	No data	46	No data	12	No data
Jan. 24	14	1	13	0	16	0
Jan. 25	15	8	8	1	15	4

population in Fish Lake. On July 17, 1967, two mudminnows were taken in the trap nearest the shore in the northwest corner of the lake. However, I did not discover the location of the major portion of the mudminnow population until August 5, 1967. Two traps which had broken free from their moorings in the lake and drifted to the south shore were found to contain several mudminnows. At the same time I discovered the inlet from South Marsh, and the movement of mudminnows into the lake from the marsh. These discoveries established the pattern for subsequent investigation on movements of the mudminnow population.

Population shift within the lake

On March 31, 1968, the ice in the lake was beginning to break up. On April 7 the lake was completely free of ice. I placed ten traps in the lake, seven in a north-south line across the lake and three along the margin of West Marsh. It very soon became apparent that a shift in population was in progress. The traps were checked on April 8. No mudminnows were captured in traps in the middle of the lake at sites where they had been taken in January. Six of the traps closer to shore, including three traps along the margin of West Marsh which had been toxic during January, had mudminnows. All fish were removed and the traps reset. On April 10 the same results were obtained. It seemed apparent that the results of June and July, 1967, when no mudminnows were taken in the open lake in several hundred trap days, were repeating. Therefore, the traps from the center of the lake were taken up and set in closer to shore to follow the movement there.

The traps were inspected 25 times at their peripheral locations between April 11 and June 11, 1968. The movement of mudminnows within the lake is shown graphically on the series of the lake diagrams (Figure 3). Arabic numerals indicate the number captured in the trap at that site, circles represent sets without captures, and the "X" represents a set with captures for which the number was not designated. Mudminnows moved first toward the shore of the lake, and then peripherally to the openings into the marshes. On April 14 all shore traps had mudminnows. The trap near the mouth of the inlet from South Marsh had 15; others had 3 to 7 with the 7 at the edge of Alvar's Marsh. On April 15 there were mudminnows in all shore traps but one. On April 17, two traps had no mudminnows; others had 1 and 2. On April 19, lake traps, except the one near the south inlet, averaged about 2 mudminnows per trap. On April 22 the traps in the lake averaged 1 mudminnow per trap (0-2). Fron April 22 on through early June, this was the pattern with most captures being made along the western portion of the north shore.

Migration of breeding adults into South Marsh

The migration of breeding adults from the lake into South Marsh was followed closely. A minnow trap placed in the channel sampled the population of mudminnows moving through the channel during the period of migration (Table 2). Each number under "Captures" represents the number of mudminnows taken by this trap since the previous inspection.

On March 31 South Marsh was still frozen and no water was flowing through the outlet to Fish Lake. On April 7 there was still ice in the marsh although it was becoming spongy and honeycombed. I placed one minnow trap in the marsh by scraping a depression in the ice. The outlet stream

Table 2. Number of breeding adult mudminnows captured in a single minnow trap in the time interval from the preceding date. Trapping was conducted in the channel connecting South Marsh with Fish Lake. Migration from lake to marsh from April 7 to May 12, 1968.

Date	Captures
April 7	Trap set
April 9	2
April 10	7
April 11	20
April 12	196
April 13	54
April 14	15
April 15	0
April 17	42
April 19	15
April 22	3
April 26	1
April 27	9
April 29	16
May 1	2
May 3	1
May 8	2
May 12	0

was flowing and one minnow trap was placed there. On April 9 the marsh was covered by water although it was still frozen below. The lake temperature was 8 C and that in the flowage from the marsh was 7 C. One male and 1 female mudminnow were captured in the marsh trap. Three were taken in the trap in the inlet. I placed two more traps in South Marsh. On April 10 activity had increased greatly. The most conspicuous development was the congregation of fish in the lake around the mouth of the inlet. Four traps there had a total of 278 mudminnows in them. I removed the left pelvic fin of these fish and released them into the lake in hopes of capturing them later in the channel or in the marsh. (Only one was recaptured and that in the channel trap the following day about 30 feet from the point of release.) Several mudminnows were captured in the marsh traps. Seven were captured in the channel trap.

April 11 showed a similar picture. April 12 represented the peak of the migration when the channel trap took 196 adult mudminnows. While the trap was removed from the inlet for the purpose of emptying it, I observed a massive movement to be in progress. Within about 30 minutes I estimated that over 1000 fish moved up the channel and disappeared into the openings through the dike into the marsh. The migration was sometimes a continuous flow in which I estimated there were a minimum of 50 fish per square foot. A massive school of fish swarmed about in the lake at the mouth of the inlet. Along with the mudminnows, brook sticklebacks, leopard frogs, mink frogs, two tiger salamanders, two painted turtles and a snapping turtle moved up the channel. The turtles were feeding voraciously on the fish.

By April 13 the activity was much reduced, and on April 14 only 15 mudminnows were taken in the inlet trap. The upstream migration continued at a reduced rate for some time. On April 22 only 3 mudminnows were taken in the inlet trap. However, one of these was a female 156 mm long, the largest mudminnow taken in all collections.

Migration of spent adults into Fish Lake

Between May 12 and June 6, 1968, no mudminnows were captured in the channel trap. Following this period the spent breeders began to move back into the lake (Table 3).

On June 6, 36 mudminnows, nearly all males, were taken in South Marsh in the channel on the marsh side of the dike. This is near the seep opening through the dike to the flowage channel leading to the lake. June 10 showed the same buildup in the marsh near the outlet but still no actual downstream movement. On June 11, 8 mudminnows were taken in the trap in the flowage channel. This small migration, nearly all males, continued until June 18. Between June 20 and July 12 the massive migration of spent adults, males and females, took place. After July 12 the migration of adults dropped off sharply but it continued at a much-reduced rate until the water in the channel froze (November 11, 1968).

Migration of young-of-the-year into the lake

On July 17 the young-of-the-year mudminnows were moving from South Marsh into the lake in large numbers (Table 4). Over 100 mudminnows were in the channel trap; no count was made of the number of fish per minute passing through the channel. On July 23 the trap contained 248 young mudminnows; they were moving at the rate of 6 per minute. On July 24 the migration was at an even greater rate than that observed on July 23. In two counts, fish passing a line in the channel numbered 114 in 15 minutes

Table 3. Number of spent adult mudminnows captured in a single minnow trap in the time interval from the preceding date. Trapping was conducted in the channel connecting South Marsh with Fish Lake. Migration from marsh to lake from June 6 to July 12, 1968. (Many is over 80.)

Date	Captures
June 6	0
June 10	1
June 11	8
June 17	12
June 18	16
June 20	Many
June 22	Many
June 24	(234)Many
June 26	Many
July 4	Many
July 8	Many
July 12	Many

Table 4. Number of young-of-the-year mudminnows captured in a single minnow trap in the time interval from the preceding date. Trapping was conducted in the channel connecting South Marsh with Fish Lake. Migration from the marsh to the lake from July 17 to September 15, 1968. (Many is over 100.)

Date	Captures
July 17	Many
July 23	Many
July 24	(248) Many
July 30	(303) Many
August 2	----
August 6	37
August 7	5
August 12	Many
August 17	----
August 19	10
August 22	0
August 26	----
August 29	35
September 2	9
September 15	2

and 64 in 10 minutes which was about 7 fish per minute. This large-scale movement continued until about July 30 when the number in the inlet traps is simply designated as "hundreds." However, the count on mudminnows passing down the channel at the time of observation was only 1.5 per minute.

It appears that water temperature affects the migration rate of the young-of-the-year mudminnows (Figure 4). This phenomenon was especially apparent between August 7 and September 2, 1968.

Between July 30 and August 7 a marked warming occurred. The inlet temperature climbed to 23 C. Movement of young-of-the-year mudminnows fell sharply to near 0 per minute and only 5 had been captured in the trap in the inlet over a 24-hour period. By August 12, following a record low of 8 C air temperature on August 11, the inlet temperature was down to 20.5 C and the young-of-the-year mudminnows were moving through the channel at the rate of 2 per minute; over 100 mudminnows were taken in the inlet traps. Another warming period with 2 days in the mid-30's raised the inlet temperature to 24 C on August 22. Again the movement of mudminnows stopped and there were no mudminnows in the channel traps. By August 26 the inlet temperature had dropped to 16 C and again the migration rate was about 2.5 mudminnows per minute; over 100 mudminnows were in the traps. On August 29 the inlet temperature was back to 21 C and movement had ceased; there were 6 mudminnows in the channel traps. However, on September 2 and September 15 the inlet temperature was down to 16 C and 18 C respectively and very few mudminnows were moving indicating the end of the mass movement around September 1. Small numbers of mudminnows continued to move until ice formed.

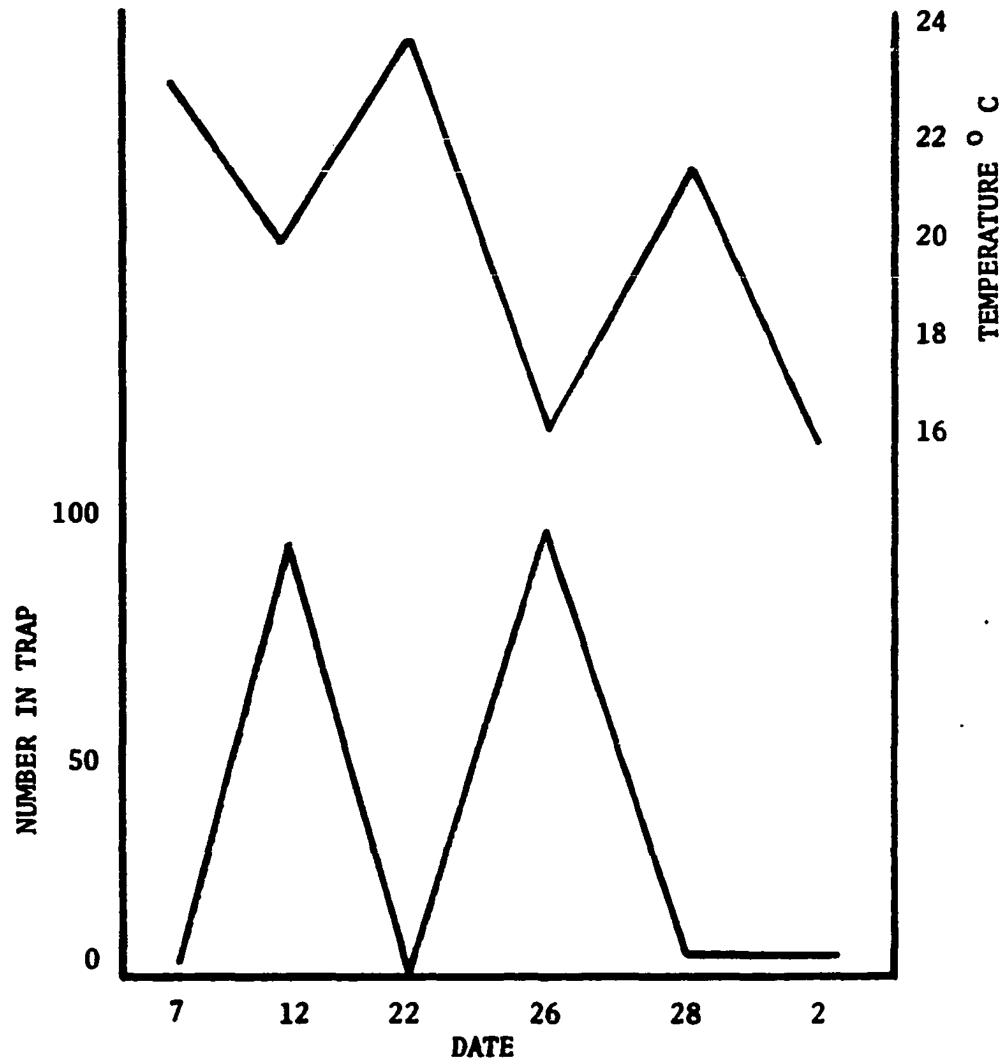


Figure 4. Relationship between water temperature and migration rate. Number of young-of-the-year mudminnows captured in a single minnow trap in the channel connecting South Marsh with Fish Lake and the temperature of the water flowing from the marsh on the same date. (August 7 to September 2, 1968).

<u>Colonization of a "new" habitat</u>

East Marsh is connected to Fish Lake only during periods of above-average water levels. Between such periods the mudminnows of the marsh are victims of the conditions there, surviving or perishing accordingly. Between June 1, 1967, and November 11, 1968, I observed this marsh regularly. During this period it underwent very drastic changes. In the late summer and fall of 1967 it dried up completely, the water table falling to 10 inches below the surface of the bottom of the channel in the marsh. It froze dry resulting in the frost going down to about 22 inches. The mudminnow population was eliminated. Melting snow and spring rains put several inches of water in the marsh but did not raise it high enough to overflow into the lake. Continuous trapping from April 10 to June 20, 1968, produced two mudminnows both of whose presence is explainable by other than winter survival in the marsh. The first was captured on April 13 and is believed to have come up in water running off from the melting snow. The bottom of the marsh was still frozen making emergence from there impossible. The second was captured on June 17. This followed a period of several heavy rains and it is likely it came up in rain water runoff.

Heavy rains during June raised the level of East Marsh. On June 18 it was within one inch of flowing into the lake. I set three more traps, two in the mouth of the outlet and one in the channel leading from the marsh. No mudminnows were taken in the traps in the marsh or the channel on June 18. On June 20 a morning rain raised the marsh to overflowing. Observations were begun within 30 minutes of the time of connection. One stickleback was in a trap in the outlet and another was seen to move through the outlet. No mudminnows appeared at that time.

June 22, 2 days after the initial connection, the outlet was flowing freely. Four mudminnows, 2 in each of the two traps in the mouth of the outlet were taken along with 30 sticklebacks, several *Physa*, 6 predaceous diving beetles, 1 giant water bug, and 2 crayfish. In the lake a semicircle of brown water extended out about 30 yards around the mouth of the inlet before it blended off to become imperceptible to the eye. That this new source of water was a stimulus there is little doubt. It seems likely that it was a chemical stimulus rather than a physical stimulus of current but this is not established. Water flowing into the lake from South Marsh did not stimulate the same responses. The reverse situation existed there where mudminnows were entering the lake through the channel from South Marsh.

The mudminnows entering into East Marsh were predominantly the age I class which had been poorly represented in previous collections (see "Age and Growth"). Collections of July 30 and August 12, 1968, are typical (Table 5).

Food and Feeding

Two factors influenced the decision to forgo a detailed analysis of the food and feeding habits of the mudminnow in this study. The method of capture used in this study resulted in most of the stomachs being empty due to the mudminnows having been in the traps for several hours before removal. Thorough studies have been performed on the food and feeding habits of the mudminnow (literature previously cited). However, 15 stomachs were examined and the contents noted as follows (Table 6): 5 contained fish (3 sticklebacks and 2 fatheads), 1 contained a dragonfly naiad, 1 contained a damselfly naiad, 9 contained *Gloeotrichia*, 1 contained *Spirogyra*, 5

Table 5. Sample of the population of mudminnows migrating from Fish Lake into East Marsh in a colonizing action. The sample consists of 71 mudminnows collected in two minnow traps in the channel connecting the marsh with the lake. Collections of July 30, 1968, and August 12, 1968, combined.

Length (mm)	Number
39	1
40-44	2
45-49	3
50-54	5
55-59	17
60-64	17
65-69	12
70-74	11
75-79	3

Mean Length: 61.5 mm; Total Number: 71

Table 6. Occurrence of food items in the stomachs of 15 mudminnows taken in January and April of 1968 from Fish Lake.

	Stomach Number														
Food Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Gloeotrichia		X		X	X	X			X		X	X		X	X
Spirogyra				X											
Damselfly naiad															X
Dragonfly naiad												X			
Canthocamptus	X			X					X		X			X	
Snails		X		X				X		X	X	X		X	X
Fish	X		X				X						X		X

contained Canthocamptus, and 8 contained snails.

The mudminnow exhibits versatility in the food it consumes. In separate studies in different habitats it has been found to feed on plants, on animals, or on both plants and animals. However, it is apparent from this study and from other studies cited that the food items, other than fish, are attached or crawling forms. Plankton is not included in the diet to any extent. In the laboratory, feeding could be observed when aquatic plants were brought in fresh and placed in the aquarium. The mudminnows fed by grazing over the surfaces of the plants. Plankton poured into the aquarium stimulated the brook sticklebacks to feed but elicited no such response in the mudminnow.

Tolerance of Adverse Conditions

In the course of this study I observed the response of the mudminnow to adverse conditions in four situations. They were oxygen depletion, drought, freezing, and the combination of drought and freezing.

Oxygen depletion

During January of 1967 the oxygen content of Fish Lake dropped from 6 ppm the first week in January to a nearly unmeasurable amount 2 weeks later. The amount of oxygen was so slight that in performing the Winkler test a single drop of sodium thiosulphate neutralized the released iodine. This condition was maintained until the ice went out on April 28.

Examination at that time showed that there had been a severe winterkill of fatheads, sticklebacks, leopard frogs, tiger salamanders, and mudpuppies. Although there were a few dead mudminnows the number was very small. Subsequent work confirmed that the large mudminnow population had survived the severe oxygen depletion very well.

It is noteworthy that with the lake nearly devoid of oxygen in 1967 no mudminnows were captured in January and none were taken in early April in minnow traps set under the ice. With the knowledge of successful trapping by this method in previous winters and again subsequently (1968) in Fish Lake it is suggested that under the condition of severe oxygen depletion the activity of the mudminnow is greatly reduced.

During the course of this study the ability of the mudminnow to survive by air breathing at the surface was demonstrated many times. Carried in open containers from the lake back to the laboratory the mudminnows would invariably survive in water where both sticklebacks and fatheads died. The mudminnows would be moving about nipping air at the surface. However, when the cover was placed on the container with little air space above the water the mudminnows perished.

Drought survival

On August 18, 1967, I visited East Marsh. The only open water was in a depression in the marsh which represented the remnant of an old drainage channel now nearly filled in. The water table of the marsh laterally from the channel was just below the surface so that water was about ankle-deep in the depressed footprint. I dipped mudminnows in the open water of the channel and also in the water which appeared among the plant fragments and roots of the sedges as they were depressed by walking about. On September 20 the only open water was in a hole about 18 inches in diameter and 10 inches deep in the channel. The water table was down to about 6 inches below the bottom of the channel. I removed 30 mudminnows from the hole in the channel. After digging several holes down among roots of the vegetation lateral to the channel I succeeded in finding one living mudminnow in the water at the water table about 10 inches below the dry marsh bottom. Thus at this time and in this situation the mudminnow was surviving a drought condition by actually avoiding it. The nature of the bottom was such that the mudminnow had maneuvered in the interspaces of the fibrous roots and peat materials and followed the water table down.

Freezing

Unlike East Marsh, South Marsh did not dry completely in the late summer and fall of 1967. A small amount of open water remained between the hummocks and in the channel in the marsh. However, the frost line extended down into the bottom. During January, 1968, I dug holes there in the attempt to trap below the ice but trapping was not possible. No mudminnows were discovered in the three holes dug through the ice and into the peat below.

In the fall of 1968 I constructed four cages and installed them, along with temperature probes, as described previously. The experiment yielded very limited information. Adequate water and good snow cover kept the frost line shallow. In four readings, three in January and one in March, 1969, the temperatures were constant as follows: -1 C at the ice surface (below about 2 feet of snow); 0 C at 6 inches; 1 C at 12 inches; and 5 C at 18 inches below the surface of the ice. The two cages removed in January yielded no mudminnows either from the ice when thawed or from the bottom by dipping and scooping there. The "dipping and scooping" was very inefficient and it cannot be stated for certain that there were no mudminnows there.

Live-traps placed in the two remaining cages in April likewise captured no mudminnows. It was previously explained that escape from the cages by going under the wire was possible.

It is significant that no dead mudminnows were found in the cages or in the marsh around them. The likelihood of survival of the mudminnows in South Marsh during the winter of 1968-1969 seems good.

Drying and freezing

East Marsh, during the winter of 1967-1968, gave an excellent opportunity to observe the effect on the mudminnow of drying and freezing of the environment.

The drying condition and the response of the mudminnow were described above. The actual temperature to which the mudminnows were exposed was not measured in East Marsh but it can be assumed that it was -1 C to 0 C to the frost line which was 22 inches below the surface of the dry marsh bottom.

No mudminnows survived this extreme condition of drying and freezing in their habitat. The marsh was trapped continuously from April 10, 1968. One mudminnow was captured in the time from April 10 to June 17 when a second one was captured. Both of these can be accounted for on the basis of passage during water runoff, first of melting ice, and then of rain water. When connection was established between this marsh and the lake, mudminnows were captured abundantly. From this experience it seems that to conclude that no mudminnows survived the drying and freezing is justified.

Parasites

A complete survey of the parasites of the mudminnows of Fish Lake was of such a magnitude that it was not attempted in this study. Three specimens were examined using the method of Hoffman described earlier. Two living flukes were found in the brain of one specimen and a sporozoan parasite was found in the gills of another. Neither the flukes nor the sporozoan appeared to be species previously identified for the mudminnow as listed and illustrated in Hoffman.

Metacercariae embedded in the skin of the mudminnow were a conspicuous feature and special attention was given to them from a quantitative viewpoint. The metacercariae induced the formation (congregation ?) of a large number of pigment cells in the skin immediately surrounding the cyst so they were readily located.

Data on 78 age II and 10 age III mudminnows are compiled (Table 7). The number of metacercariae varied from 0 to 494 per fish. There appeared to be no relationship between age or size of the mudminnows and infection rate in the two age classes.

Breeding Habits

The general pattern of breeding of the mudminnow in Fish Lake was not markedly different from that reported in the literature from the eastern United States. The basic requirement of vegetation as a substrate upon which the eggs were deposited was met. The sedge hummocks and bog sedges served as well as the grassy backwaters described by Peckham and Dineen (1957) and the vegetation-clogged drainage ditches described by Adams and Hankinson (1928).

The mudminnow in Fish Lake spawned nearly a month later than in Indiana and other areas reported on. All reports in the literature

Table 7. Parasites of the mudminnow. Per cent infection of mudminnows of a range of sizes at age II and age III with the range and average number of metacercariae in each size and age category. Collected in Fish Lake in April, 1968.

	Age II Fish				Age III Fish			
TL of Fish	No. Fish	Mean	Range	Infection (%)	No. Fish	Mean	Range	Infection (%)
66-70	6	33.3	2-73	100				
71-80	16	49.7	0-157	93.7				
81-90	30	49.4	0-290	93.3				
91-100	21	63.0	0-494	76.2				
101-110	4	13.0	1-26	100				
111-120	1	15.0	---	100	2	37.0	0-74	50
121-130					4	22.5	7-68	100
131-140					4	75.0	3-235	100

Total age II fish: 78; Average infection: 91% Total age III fish: 10; Average infection: 90%

describe it as spawning in March or April. Peckham and Dineen found all females gravid on April 9, 1954, and all females spent by April 29, 1954. In this study the first partially spent female I captured was trapped on May 21, 1968. Examination of female mudminnows collected on May 1, 3, 8, 12, and 13, 1968, showed them all to be carrying eggs tightly held together in ovarian tissue. On May 21 most females carried eggs but the appearance of partially spent females was noted. On May 24 the same observation was made. On May 26 most of the females taken had spawned. On May 29, June 3, and June 4 all females collected were completely spent. On June 6 one female carried a few eggs. I found no eggs after June 6, 1968.

It is interesting to note the temperature conditions in South Marsh during reproduction. On May 1, 1968, when most mudminnows were in the marsh, and before spawning had begun, the surface water was 18 C; at 4 inches below the surface it was 10 C; at 10 inches below the surface and under about 2 inches of litter and bottom ooze, the bottom was still frozen. By May 26, most females had spawned. The temperature at 4 inches was still 10 C and the bottom was still frozen at about the same level as before. On June 17 the marsh surface was 22 C. Sixteen inches below the surface it was 16 C and the very last of the ice layer was at 24 inches below the surface. The ice went out on June 17-18, 1968. A thin layer of ice, easily punched through with a net handle was present on the 17th and gone on the 18th.

By the time the ice went out the adult mudminnows, especially the males, were moving back into the lake. Spawning was substantially completed and the first fry had been dipped from the marsh on June 11. Spawning must have been in water at about 10 C, the temperature at 4 inches.

All breeding mudminnows in the spring of 1968 in Fish Lake were 2 years old (age II) or older. This contrasts with findings, cited above, of breeding at age I in Indiana and Michigan.

Age and Growth

Consideration of age and growth of the mudminnow in Fish Lake involves: methods used to determine age; determination of size range in age groups 0 and I and size range by sex and age in age groups II, III, and IV; and a comparison of size and rate of growth between Fish Lake and Judy Creek.

Method of aging

I examined otoliths from fish in the fresh condition, after preservation in alcohol and after preservation in formalin. Because all of the mudminnows from early collections had been preserved in formalin it was a valuable discovery that, contrary to generally held opinion, otoliths from mudminnows thus preserved were clearly readable. The otolith in Figure 5 is from an age IV mudminnow collected and preserved in 4% formalin in April, 1968, and examined and photographed in July, 1971.

Regardless of the method of handling, the clarity of the annuli varied from specimen to specimen making a certain amount of subjective interpretation necessary. For this reason it was advantageous to examine a developmental series within the first year to establish the nature and the extent of the growth of the first year (Figure 6, a-d). With this one-year-growth established subsequent rings could, in almost all cases, be distinguished. During the first month a tiny, lobular sacculith was formed (6a). At this time it was clear and transparent. As development continued it became more dense with transitory concentric rings apparent (6b). By 5-6 months it was quite dense (opaque) and had the appearance which it maintained as the center of the sacculith (6c). In the winter a narrow, rather clear, band was formed which was followed by a wider, opaque band laid down in the spring and summer. Thus an annulus, marking the end of the first year and beginning of the second year, was delineated (6d). Each subsequent year was marked by the pair of alternating clear and opaque rings.

One precaution was necessary. The combination described was obliterated to a greater or lesser extent in older specimens by the elimination of the clear band of the first year. Thus the whole central core, rather than the first distinct ring, represented the first year. Reading the first distinct ring then resulted in dropping the second year and subsequent readings were a year below actual age. Because the first year constituted such a major proportion of the width of the otolith and because it was fairly uniform in size it was possible to measure that distance on the older cores to aid in establishing the first year of growth.

The ages established by examination of the otoliths seemed reasonable and consistent with the age structure interpreted from length-frequency analysis. In general, an increase in the number of annuli in the otoliths was accompanied by an increase in length of the fish.

I also used length-frequency in the attempt to establish the age structure of the mudminnow population in Fish Lake. Combining age data from otoliths with size data from length measurements gave a clear picture of the age structure of the population and at the same time emphasized the limitation on the use of the length-frequency method on the mudminnow

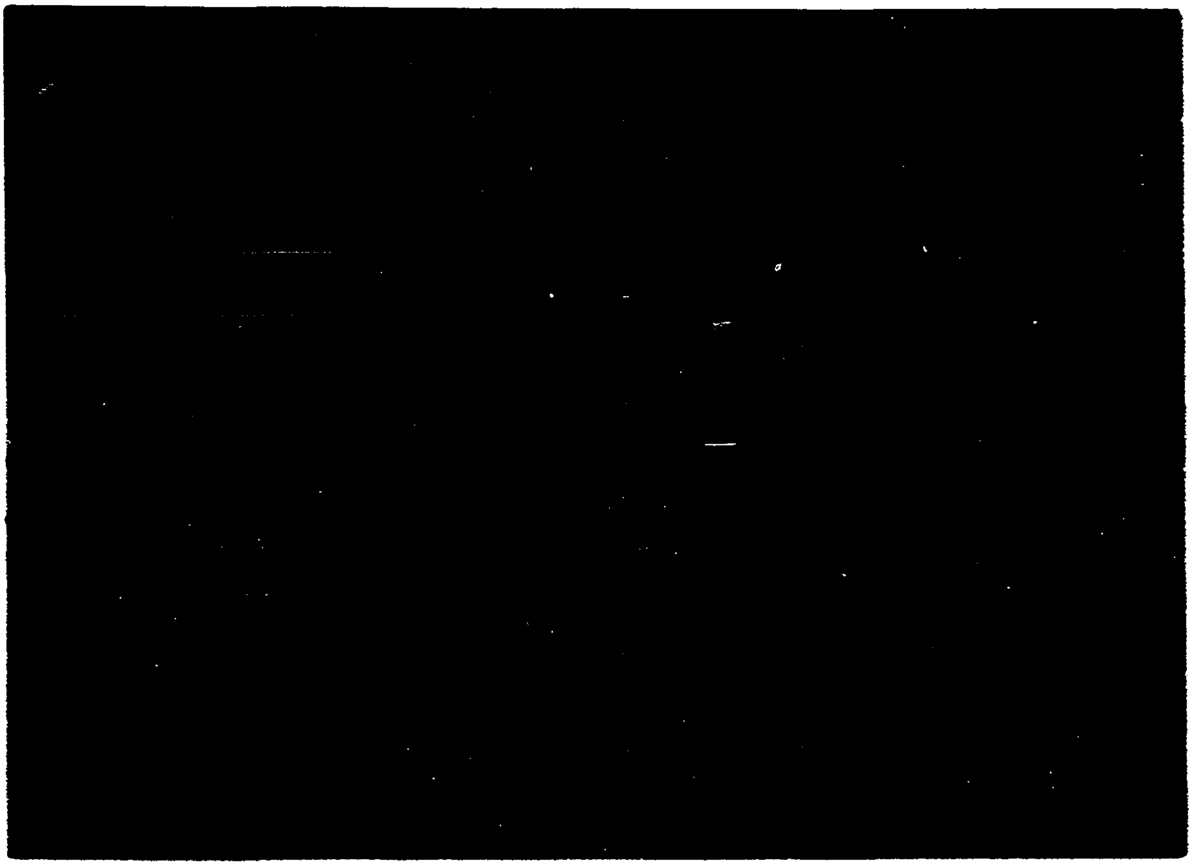


Figure 5. Otolith from mudminnow preserved in formalin from April, 1968, to July, 1971. (Age IV; in glycerin with side lighting; 40X)

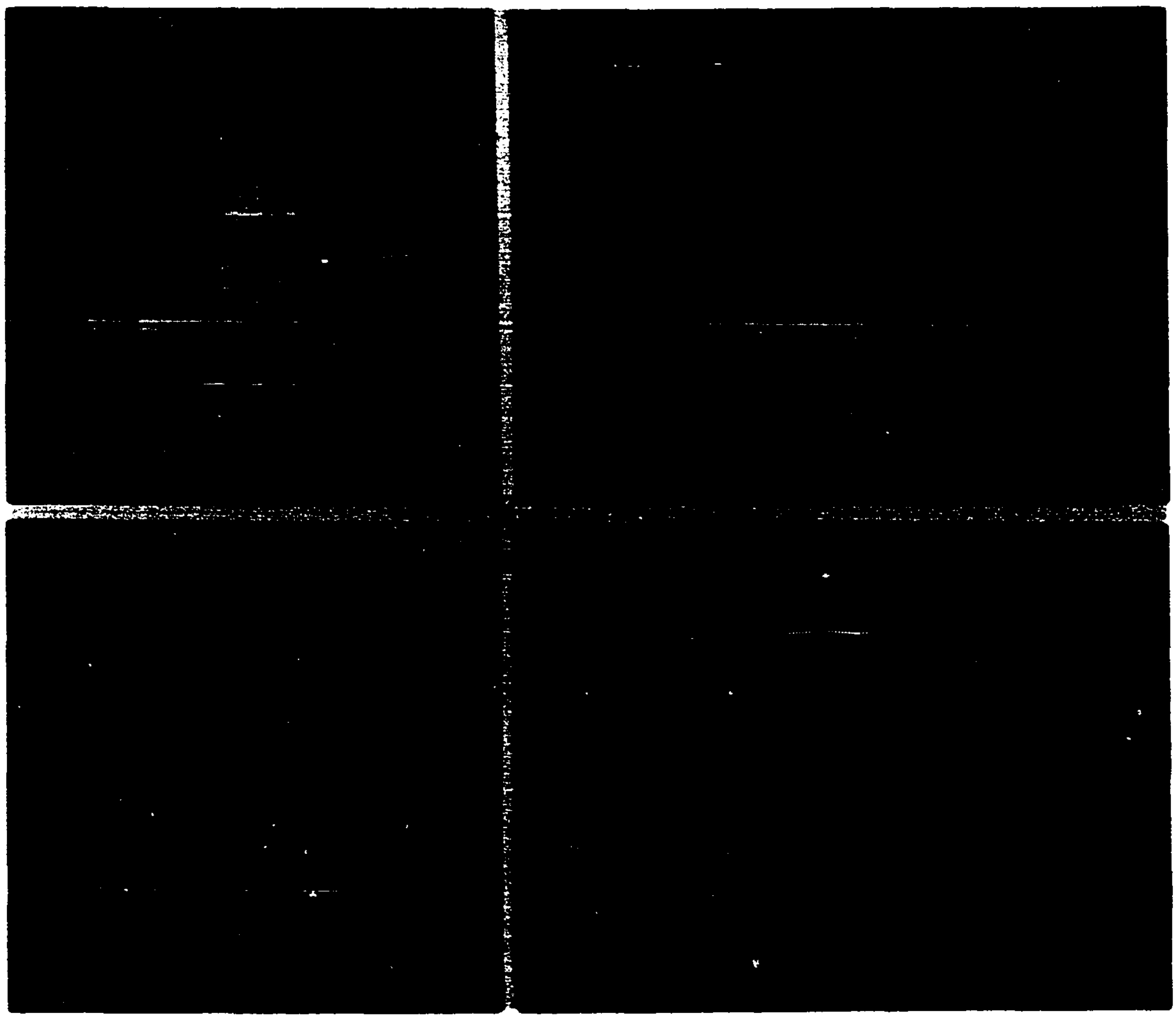


Figure 6. Development of the otolith in the mudminnow. Figure 6a, July 17, 26 mm (1+ mo.); b, Aug 12, 32 mm (2+ mos.); c, Jan. 7, 45 mm (5+ mos.); d, July 30, 61 mm (13+ mos.). From Fish Lake. (In glycerin with side lighting; 40X).

(Table 8). Fish of the same age varied considerably in size and there was overlap between smaller fish of one age category with larger fish of the age category below and between larger fish of the age category and the smaller fish of the age category above.

I examined scales in several media (water, alcohol, xylol, and glycerine) and after staining with two different stains (eosin and carmin). As others have found previously (Peckham, 1955; Van Oosten, 1941), no annuli could be distinguished in the scales. Scales of known-age fish of various ages were examined side by side (Figure 7). Even knowing approximately where the annulus would be expected to appear did not help.

Age and size

Age and size considerations were closely tied to behavioral patterns. They are discussed in three categories: age 0, age I, and breeding fish (age II, III, and IV).

Several large samples of young-of-the-year mudminnows were collected as they migrated through the channel from South Marsh into Fish Lake. The sample taken July 24, 1968, consisting of 248 fish is typical (Figure 8). Two features of the data are especially notable: the wide range in size, 32-60 mm; and the bimodal form of the population with a grouping at 42-44 mm and another at 48-52 mm.

That young-of-the-year (age 0) mudminnows have a size range this great is supported by otolith examination (Table 8). The size range of 30 mudminnows selected for size range from among several collections of age 0 fish was 19-63 mm. The explanation for the wide range lies, at least in part, in difference in age. Examination of the spawning females on the

Table 8. Size distribution by age and in ages II, III and IV by sex of representative samples of the mudminnow population of Fish Lake as revealed by otolith examination.

	Number							
	Age 0	Age I	Age II		Age III		Age IV	
Length (mm)			M	F	M	F	M	F
19-24	4							
25-29	0							
30-34	1							
35-39	4							
40-44	8							
45-49	2	1						
50-54	6							
55-59	4	6						
60-64	1	7	1					
65-69		10		5				
70-74		8		5				
75-79			1	12				
80-84			2	15				
85-89			3	15	1			
90-94			7	14	1	1		
95-99			3	10				
100-104			1	6	3			
105-109				5	3	2		
110-114				9	1	2	4	
115-119						2	3	
120-124				2		7	4	
125-129						4	1	
130-134						5	1	
135-139						2		1
140-144						1		3
145-149								1

breeding grounds showed that, although most spawning was accomplished in a period of 1 week (May 21-26), later spawning did occur (June 6). Other possible explanations would be sexual dimorphism and individual differences.

The bimodal curve was a regular feature of the age 0 samples. Comments on it are conjectural at this time. Examination of the gonads, and search for genital tubules and for genital pores in the attempt to determine sex in this age group proved futile. However, it will be shown that the adult mudminnows in the Fish Lake population show a marked sexual dimorphism in size and it is possible that this dimorphism first appears early in development.

The 1-year-old mudminnows (age I) first appeared as an identifiable group in late July, 1968, when, following a series of heavy rains, East Marsh began to overflow into Fish Lake. This created a "new" habitat which was quickly exploited by several species of animals as previously described. On July 30, I collected and measured 48 mudminnows. The size range was 39-78 mm with a mean of 61.7 mm; on August 12, I collected 23 fish having a size range of 49-78 mm and a mean of 61.0 mm. Table 5 includes the two collections treated as a single sample. The size range of the sample was 39-78 mm with a mean of 61.5 mm. By length-frequency examination this appeared to represent a new group of fish smaller than breeding males or females seen earlier in the breeding migration and larger than the young-of-the-year moving into the lake from South Marsh.

Otolith examination of a selected sample of these fish confirmed that the sample was of predominantly age I mudminnows but that a few age 0 fish were involved in the mid-summer colonization (Table 9). The sample chosen consisted of 42 mudminnows with the size range of 44-72 mm. Thirty-two fish

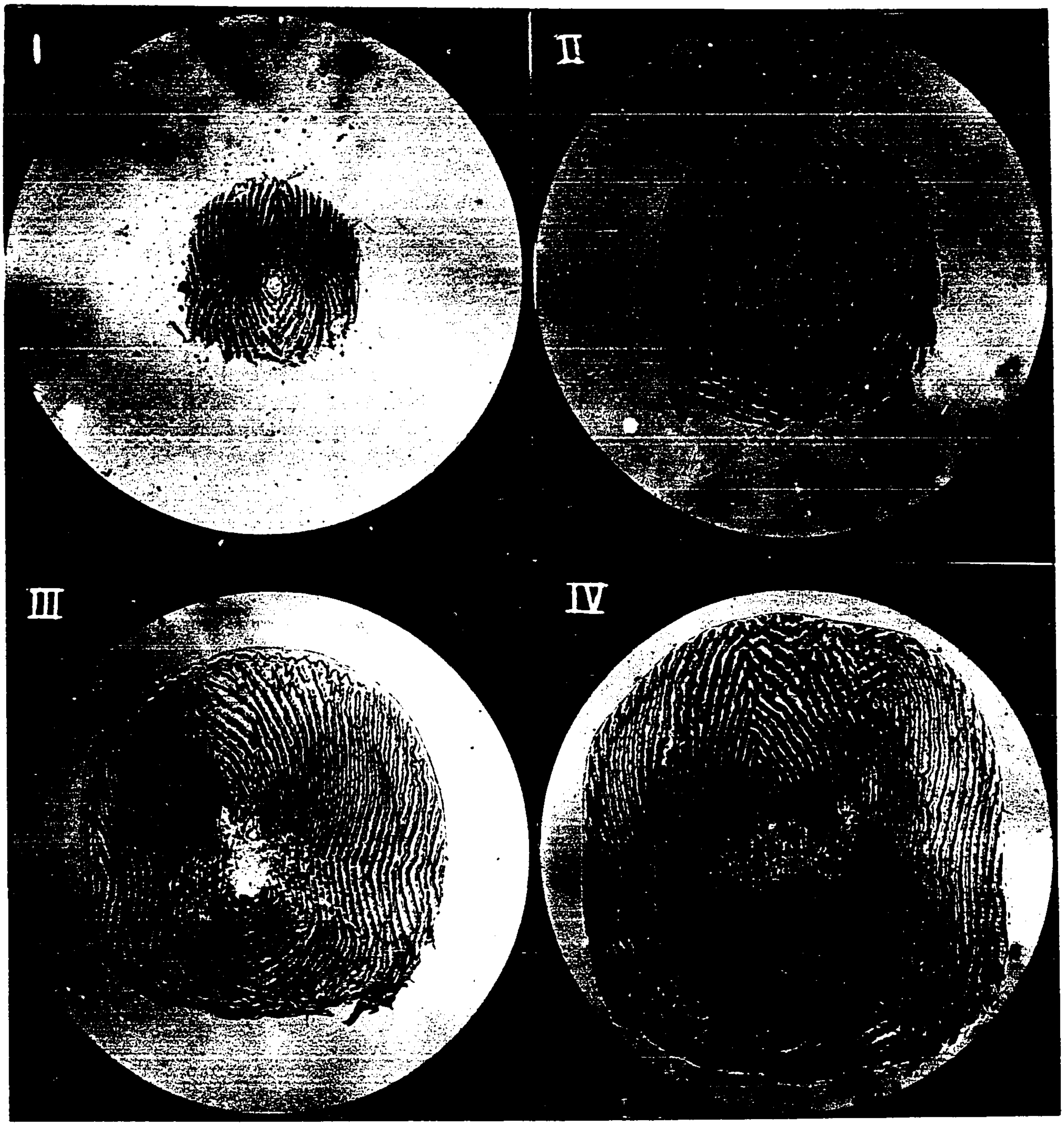
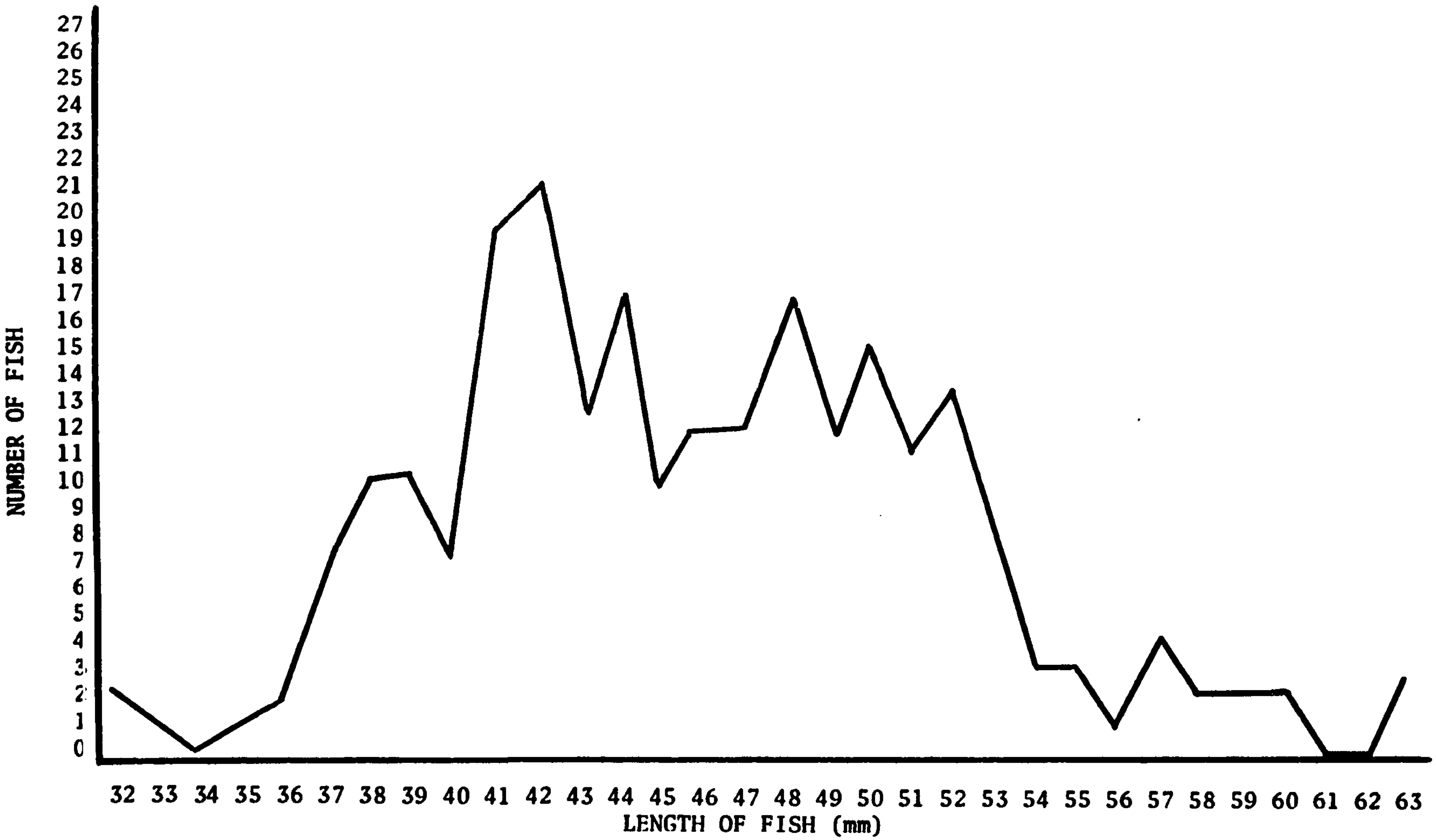


Figure 7. Scales from mudminnows of ages I-IV from Fish Lake, January 1968. Lengths 54 mm, 79 mm, 106 mm, and 122 mm for ages I, II, III, and IV respectively. (In glycerin; about 20X.)

Figure 8. Representative sample of the population of young-of-the-year mudminnows migrating into Fish Lake from South Marsh. The sample consists of 248 mudminnows captured over a 24-hour period in one minnow trap placed in the channel connecting South Marsh with Fish Lake. July 24, 1968.


NUMBER OF FISH
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63
LENGTH OF FISH (mm)

were of age I with the size range of 47-72 mm and the mean length of 62.4 mm; 10 were of age 0 with the size range of 44-56 mm and the mean of 51.0 mm.

Data for analysis of breeding adult (age II, III, and IV) mudminnows were from collections made in April, 1968, as the fish migrated to the spawning grounds. These fish were analyzed to determine the relationship between size and sex and to determine the size range within age categories by sex.

There appears to be a marked difference in size between the sexes in the mudminnow population in Fish Lake. Length-frequency analysis of the two sexes is shown graphically in Figure 9 for males and Figure 10 for females. The range in size of 146 males is 62-122 mm compared with the range in 121 females of 64-156. The mean for males is 79.7 mm and for females 94.9 mm.

In a much smaller sample which was divided into age II, age III, and age IV groups by otolith examination the pattern persists in values for size ranges (Table 10). At age II males ranged from 62-104 mm and the females ranged from 66-122 mm; at age III, males, 91-113 mm and females 108-138 mm; and at age IV, males, 110-134 mm and females, 141-143 mm. The mean values for age II, however, are 89.0 mm for males and 86.0 mm for females. In this case I feel that the range values are more representative of the actual population structure. I feel that chance or an unrecognized bias entered into the selection of specimens for otolith examination either toward selecting larger males or smaller females or both.

Comparison with Judy Creek (Indiana) population

The data presented in Table 10 are from collections made by traps placed

Table 9. Length and number of age 0 and age I mudminnows colonizing East Marsh. Sample consists of 42 fish selected for otolith examination from collections taken in two minnow traps placed in the channel connecting the marsh with Fish Lake. July 30 and August 12, 1968.

	Number	
Length (mm)	Age 0	Age I
44	2	0
45-49	1	1
50-54	4	0
55-59	3	7
60-64	0	6
65-69	0	10
70-74	0	8

Total: age 0, 10; age I, 32.
Range: age 0, 44-56 mm; age I, 47-72 mm.
Mean: age 0, 51.0 mm; age I, 64.4 mm.

in the channels during periods of migration between Fish Lake and its associated marshes. They comprise eight age 0 collections made between July 15 and October 19, one age I collection of July 30, and 131 breeding males and females from collections made in April, 1968.

The data of Table 10 are compared graphically with data of Peckham (1955) on the mudminnow population of Judy Creek (Indiana) in Figure 11. The bar graph (solid bars for Fish Lake and open bars for Judy Creek) shows the mean values for total length at several ages in the two populations. The mean size of age 0 mudminnows in July (1 month old) from Fish Lake, 46 mm, is much higher than that from Judy Creek, 17.8 mm, in May (1 month old). This suggests that growth in Fish Lake was at a much greater rate. However, further examination of the data of Figure 10 shows that the mudminnows of Fish Lake appear to be larger in July than in August and larger in August than in October (46 mm, 45.8 mm, and 44.7 mm respectively). The explanations for these discrepancies probably lie in the method of collecting. By placing the traps in the channel leading from the marsh it is likely that sampling was highly selective of those fish which were first spawned and/or those which were most precocious in growth as well as in attaining the stimulus to migrate; also, the pores in the plastic mesh of the traps were large enough to allow the smallest fish to escape. Mudminnows at age 4 months and at age I from Fish Lake and Judy Creek are very similar. In age II and age III mudminnows, however, available data indicate that the mudminnows in Fish Lake attain larger size that those of Judy Creek.

Reproductive Potential

The data on egg counts from 116 adult female mudminnows taken in April,

Figure 9. Size distribution of breeding male mudminnows migrating into South Marsh from Fish Lake in April, 1968. Sample selected from collections made using several minnow traps in and near the channel leading from the lake into the marsh. (00 - 22 on right half of figure, + 100). (Sample size, 146; range in length, 62-122 mm; mean, 79.7 mm).

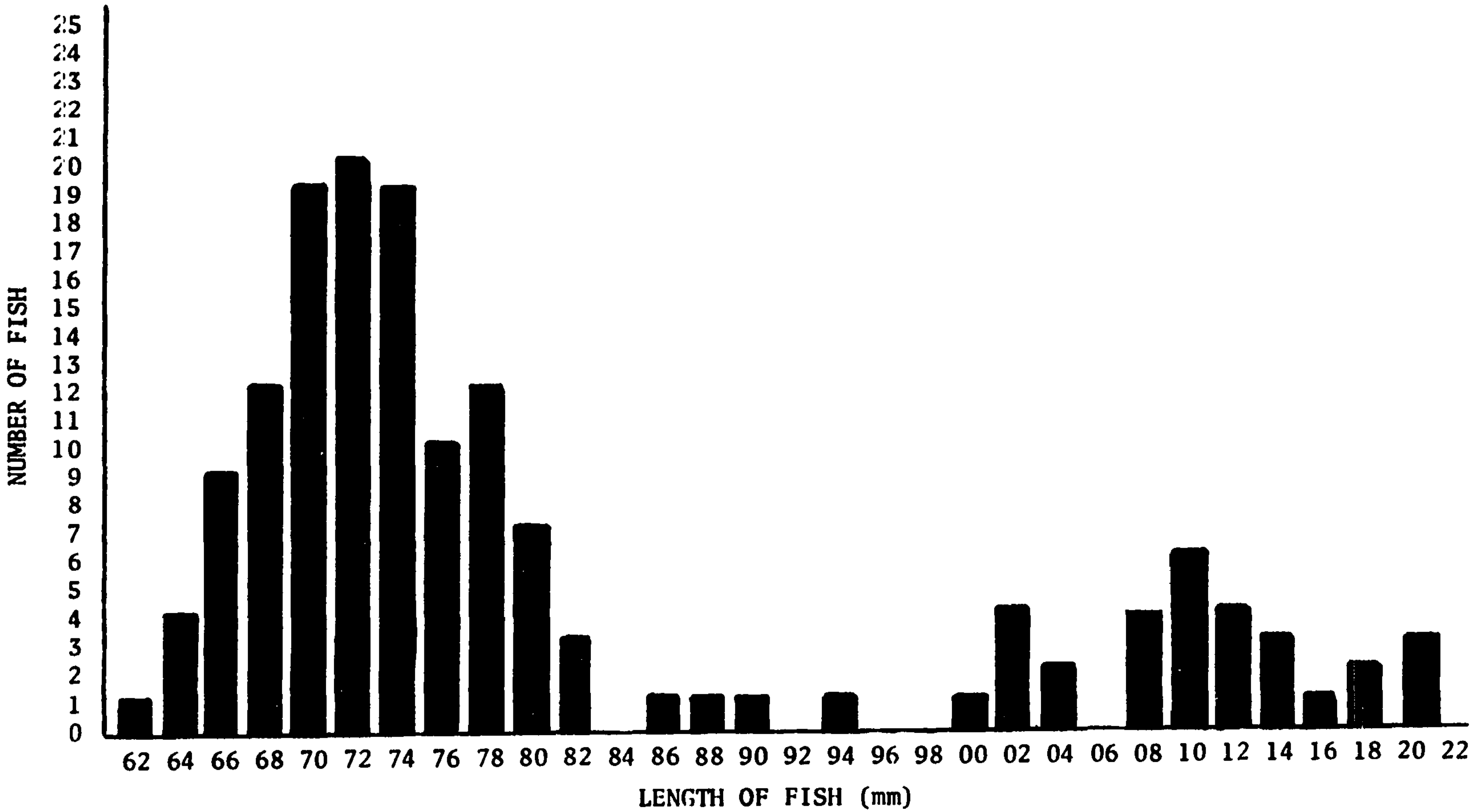

NUMBER OF FISH
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 00 02 04 06 08 10 12 14 16 18 20 22
LENGTH OF FISH (mm)

Figure 10. Size distribution of breeding female mudminnows migrating into South Marsh from Fish Lake in April, 1968. Sample selected from collections made using several minnow traps in and near the channel leading from the lake to the marsh. (Sample size, 121; range in length, 64-156 mm; mean, 94.9 mm).

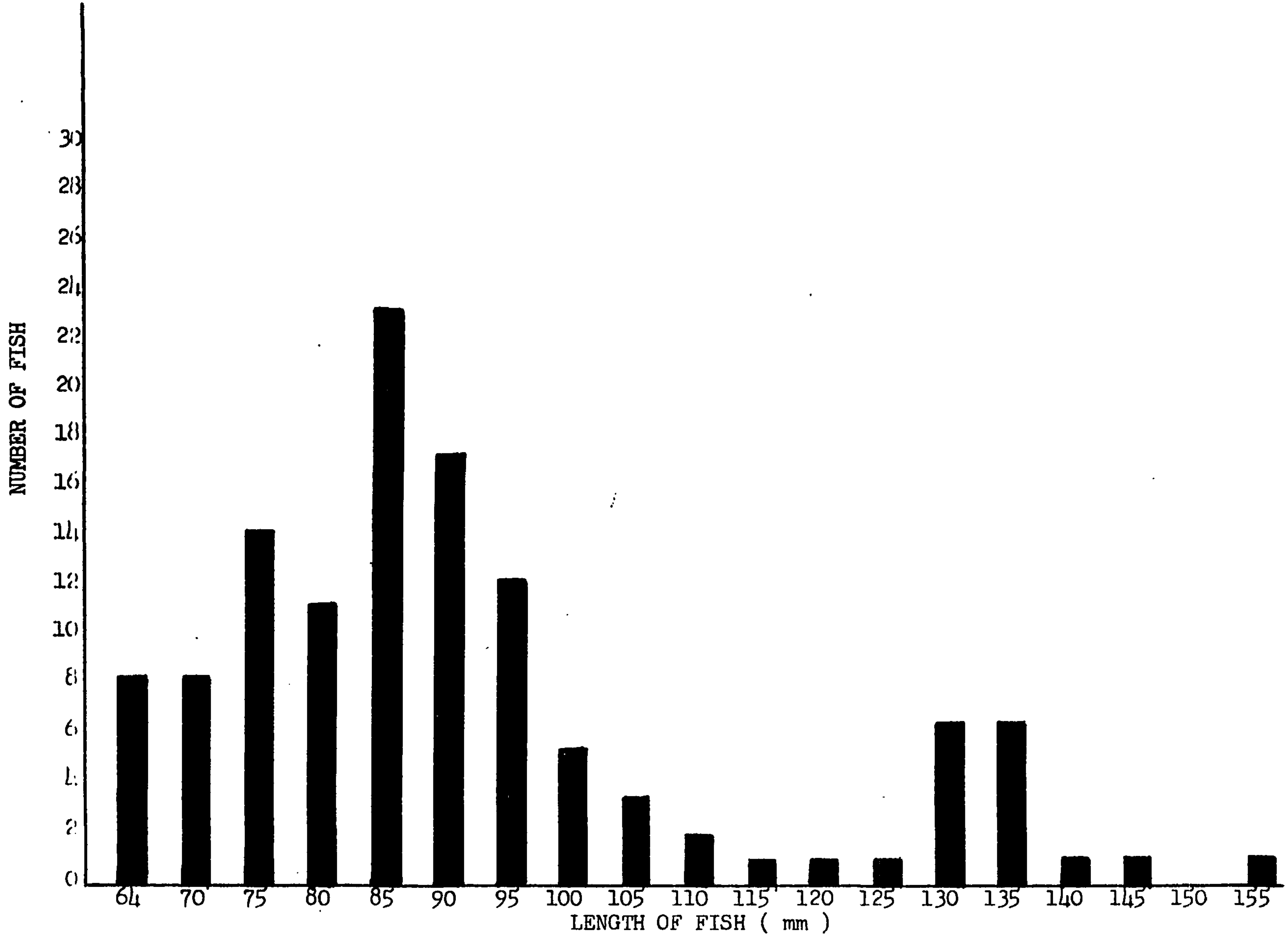
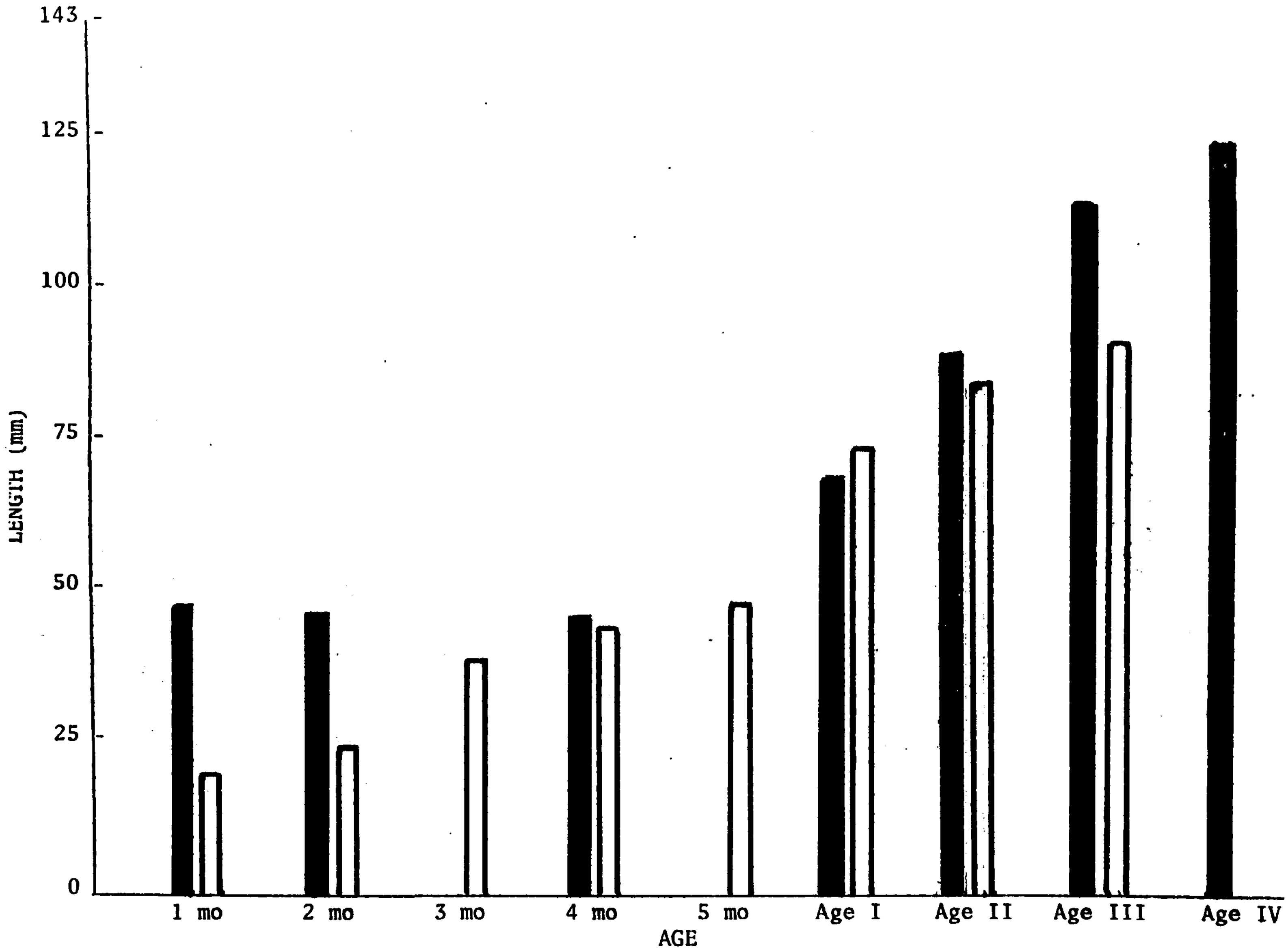

NUMBER OF FISH
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
64
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
LENGTH OF FISH (mm)

Table 10. Range and mean of seven age 0 collections from July 15, 1968, to October 19, 1968; one age I collection of July 30, 1968; and a selection from several collections of males and females of ages II, III and IV taken in April, 1968.

Age	Date	Number	Range	Mean
0	July 15 + 22	308	36-56	45.1
0	July 24	247	32-57	46.0
0	July 30	300	38-60	46.8
0	August 6	38	21-64	41.8
0	August 12	229	34-61	45.8
0	August 26	114	41-57	47.4
0	October 19	247	34-63	44.7
I	July 30	32	47-72	64.4
II (M)	April	18	62-104	89.0
III (M)	April	9	91-113	102.0
IV (M)	April	14	110-134	120.0
II (F)	April	77	66-122	86.0
III (F)	April	11	108-138	128.0
IV (F)	April	2	141-143	142.0

Figure 11. Comparison of average sizes of mudminnows at various ages from Fish Lake and from Judy Creek (Indiana). Data on Fish Lake from Table 10. Data on Judy Creek from Peckham (1955) in Carlander (1969). (Fish Lake, solid bar; Judy Creek, open bar.)


143
125
100
75
50
25
0
LENGTH (mm)
1 mo
2 mo
3 mo
4 mo
5 mo
Age I
Age II
Age III
Age IV
AGE

1968, from Fish Lake show a considerable variation in number of eggs from fish of the same age (Table 11) but a general increase in egg number with increase in age. In age II fish the number varies from 216 to 1914 eggs per fish with the mean of 1249; in age III, 498-3828 with mean of 2125; and in age IV, 1620-3618 with mean of 2678. Early in the work on this project it was thought possible that the number of eggs might be used as a device for aging the mudminnow. The great variation in egg number in each age category and the overlap in egg number between age categories demonstrate that egg count is not a reliable indicator of age in the mudminnow in Fish Lake.

The number of eggs produced in each size category also shows considerable variation (Table 11). In spite of this variation it is apparent that egg number is related to the size of the fish (Figure 12). The scatter diagram demonstrates a positive correlation between egg number and length of the fish.

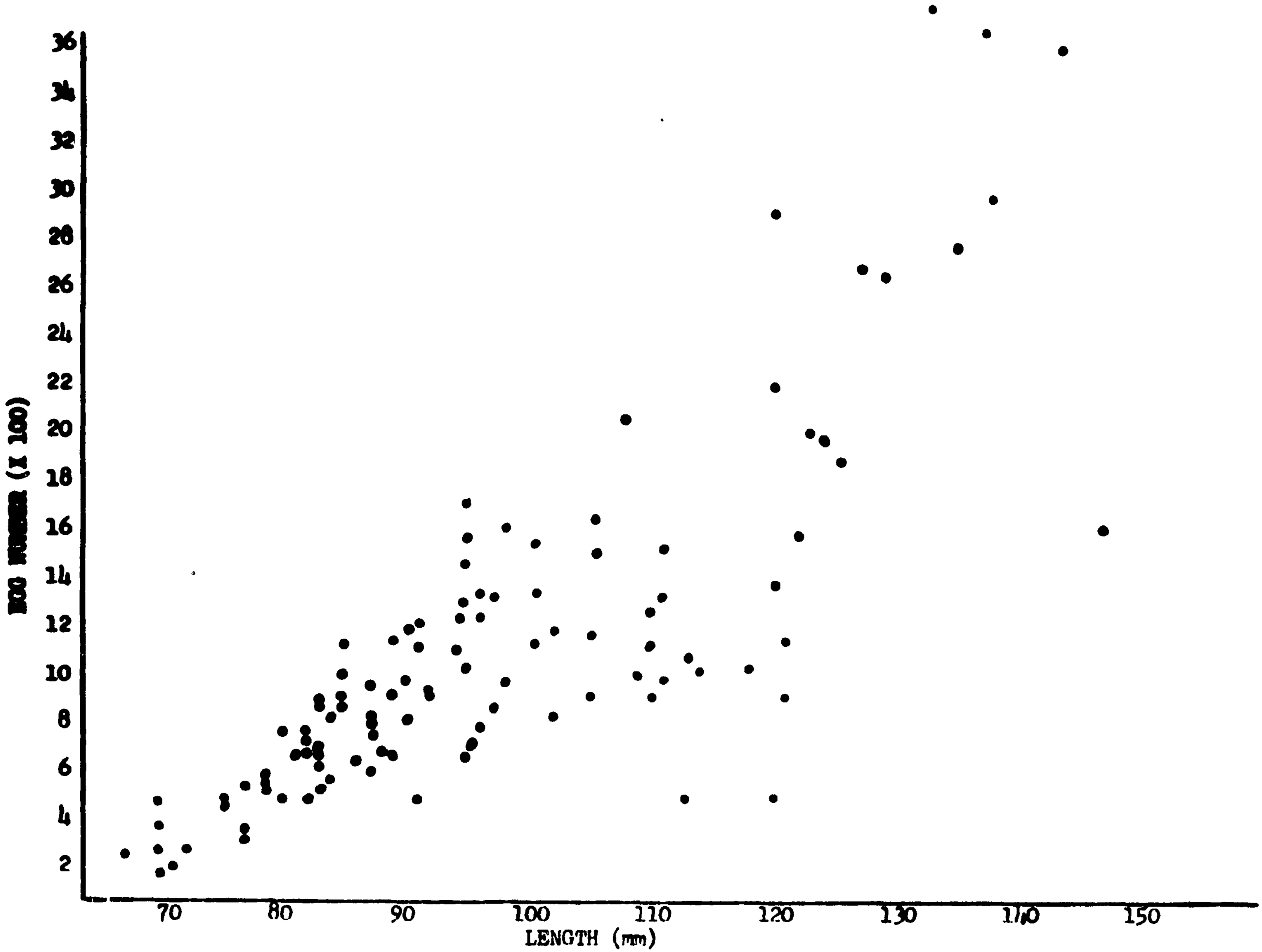
I attempted to compare reproductive potential of the Fish Lake population with those of Judy Creek (Indiana) as reported by Peckham (1955) and Red Creek (New York) as reported by Westman (1944). The following observations were made. All reproductive mudminnows in Fish Lake were age II or older whereas the other populations had some reproduction at age I. Mudminnows in Fish Lake attain a larger size before they reproduce than either of the other populations (size range in smallest reproductive category: 66-69 mm, Fish Lake; 52-57 mm, Judy Creek; 46-49 mm, Red Creek).

The breeding mudminnows in Fish Lake attain larger size than those reported for Judy Creek and Red Creek (size range in largest reproductive category: 147 mm, Fish Lake; 81-91 mm, Judy Creek; 101-108 mm, Red Creek).

Table 11. Range and mean of number of eggs produced by mudminnows with size range from 66 to 147 mm and in age groups II, III and IV. From Fish Lake in April, 1968.

Length (mm)	Age	No.	Number of eggs per female: Range	Number of eggs per female: Mean
66-69	II	5	216-446	324
70-74	II	5	232-486	380
75-79	II	10	460-788	539
80-84	II	15	510-926	701
85-89	II	15	618-1162	879
90-94	II	13	504-1476	1088
95-99	II	10	670-1756	1255
100-104	II	5	864-1576	1231
105-109	II	5	888-1664	1254
	III	1	-	2084
110-114	II	7	924-1914	1249
	III	2	498-1545	1022
115-119	III	1	-	1034
120-124	II	1	-	1388
	III	7	512-2942	1634
125-129	III	4	1907-2688	2330
130-134	III	5	2014-3828	2854
135-139	III	2	3018-3642	3330
	IV	1	-	2796
140-144	IV	1	-	3618
145-147	IV	1	-	1620

Figure 12. Scatter diagram of length and egg count of 116 age II, age III, and age IV female mud-minnows from Fish Lake. April, 1968.


EGG NUMBER (X 100)
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
70
80
90
100
110
120
130
140
150
LENGTH (mm)

In cases where size categories overlap, the number of eggs produced per female is greater in both Judy Creek and Red Creek populations than in the Fish Lake population. However, the larger females of Fish Lake produce more eggs (top of range: Judy Creek, 1489 eggs; Red Creek, 2286 eggs; Fish Lake, 3828 eggs).

Length and Weight Changes Resulting from Preservation

All mudminnows collected previous to 1971 had been preserved in 4% formalin. I wished to establish a formula by which the live length and weight of these fish could be determined.

Sixty-one mudminnows were used in the study and treated as described above. Preservation in 4% formalin resulted in a 3.36% decrease in length after 75 days in preservation (Table 12). Larger fish lost a greater percentage of length; the average of the 18 larger fish was 4.8% decrease while the average of the 16 smaller fish was 2.85% decrease.

The mudminnows gained an average of 8% in weight as a result of being preserved in 4% formalin (Table 13). However, variation in recorded weights was so great, especially among smaller fish, that further use of the data seemed unjustified.

Fish Lake and its Associated Marshes

Early in the study of the ecology of the mudminnow in Fish Lake I discovered that the adjacent marshes were intimately associated with the lake in the life history of the mudminnow. Therefore the discussion of the habitat will include descriptions of four communities: Fish Lake; West Marsh, an extension of the lake; East Marsh which is generally isolated from the lake; and most interesting of all, South Marsh which is connected to the

Table 12. Length change in mudminnows resulting from preservation in 4% formalin for 30-75 days. (Measurements in mm).

Length live	Length preserved	Loss	Per cent
126	118	8	6.3
117	110	7	5.9
116	112	4	3.4
115	109	6	5.2
113	107	6	5.3
104	99	5	4.8
102	97	5	4.9
100	96	4	4.0
99	96	3	3.0
99	95	4	4.0
94	90	4	4.2
92	88	4	4.3
87	81	6	6.8
84	80	4	4.7
80	76	4	5.0
80	75	5	6.2
78	74	4	5.1
73	70	3	4.1
52	50	2	4.0
51	50	1	1.9
50	49	1	2.0
49	48	1	2.0
49	47	2	4.0
48	47	1	2.0
47	46	1	2.1
47	45	2	4.2
46	46	0	0.0
46	45	1	2.1
46	45	1	2.1
44	43	1	2.2

Table 12. (Continued).

Length live	Length preserved	Loss	Per cent
44	43	1	2.2
43	43	0	0.0
43	42	1	2.3
43	41	2	4.6
43	41	2	4.6
42	41	1	2.3
42	41	1	2.3
42	41	1	2.3
42	41	1	2.3
42	41	1	2.3
42	41	1	2.3
42	40	2	4.7
42	40	2	4.7
41	40	1	2.4
40	40	0	0.0
40	39	1	2.5
40	38	2	5.0
40	37	3	7.5
39	39	0	0.0
39	38	1	2.5
39	38	1	2.5
39	38	1	2.5
39	37	2	5.1
39	37	2	5.1
39	37	2	5.1
38	37	1	2.7
38	37	1	2.7
37	37	0	0.0
36	36	0	0.0

Table 13. Weight change in mudminnows resulting from preservation in 4% formalin for 30-75 days. (Weights in grams).

Weight live	Weight preserved	Gain (- Loss)	Per cent
20.90	23.06	2.84	13.6
18.51	20.15	1.64	8.8
17.71	20.26	2.55	14.4
15.50	17.46	1.96	12.6
14.55	16.31	1.76	12.1
13.06	14.20	1.14	8.7
12.50	14.03	1.53	12.2
10.95	12.00	1.05	9.6
10.63	11.75	1.12	10.5
10.52	11.14	.62	5.9
10.33	10.11	- .22	2.1
8.21	8.84	.63	7.7
7.13	7.40	.27	3.8
6.26	6.71	.45	7.2
5.45	6.07	.52	9.7
4.43	5.81	.38	7.0
4.32	4.60	.28	6.5
4.11	4.17	.06	1.4
1.28	1.44	.16	12.5
1.25	1.36	.11	8.8
1.04	1.00	- .04	3.7
.99	1.04	.05	5.0
.97	1.10	.13	13.3
.95	1.06	.11	11.5
.94	1.00	.06	6.3
.92	.76	- .16	17.4
.90	.99	.09	10.0
.90	.80	- .10	11.1
.87	.90	.03	3.4
.83	.83	.00	0.0

Table 13. (Continued).

Weight live	Weight preserved	Gain (- Loss)	Per cent
.82	.88	.06	7.3
.77	.79	.02	2.6
.76	.80	.04	5.1
.75	.80	.05	6.5
.75	.76	.01	1.3
.75	.72	- .03	4.0
.73	.75	.02	2.7
.70	.79	.09	12.1
.70	.70	.00	0.0
.69	.76	.07	10.1
.67	.67	.00	0.0
.64	.68	.04	6.3
.64	.63	- .01	1.6
.63	.67	.04	6.4
.63	.52	- .11	17.5
.62	.68	.06	9.7
.62	.72	.10	16.1
.62	.60	- .02	3.2
.61	.60	- .01	1.6
.61	.45	- .16	26.2
.61	.53	- .08	13.1
.61	.69	.08	13.1
.60	.64	.04	6.6
.60	.60	.00	0.0
.56	.59	.03	5.2
.54	.60	.06	11.1
.54	.50	- .04	7.4
.51	.56	.05	9.8
.46	.51	.05	10.9

lake by a small flowage from the marsh to the lake.

Fish Lake, its physical attributes

The following data are in part from the Minnesota Division of Game and Fish, Section of Research and Planning, Fisheries Lake Survey Reports (1960). Where not evident, credit is so given.

The lake is designated Fish Lake (5-196); T.34N.; R.23 W.; S.25, 26, 35, 36; located near the village of Bethel; Anoka Co.; Minnesota. The lake was mapped on June 4, 1959, and surveyed September 8-11, 1959. One other observation, that a dissolved oxygen determination, was made on December 15, 1955. (No value was given.)

The area of the lake proper was determined to be 332 acres. The entire area of the lake was classed as littoral since it was less than 15 feet in depth throughout. They cited a maximum depth of 10 feet and a median depth of 3 feet. A resident also reported a depth of 10 feet for the lake. In the course of the present work I failed to find over 6 feet of water at any point in the lake. Either my soundings simply excluded the 10-foot area or it has become filled in.

The broad expanse of the lake, about 60%, has a depth of 5 to 6 feet. The remainder is from 0 to 4 feet.

The survey reported that there were no inlets to the lake but cited residents reference to an outlet through West Marsh to Cedar Creek during high water. For several years the outlet has not functioned due to the closure of a culvert under the road along the west side of West Marsh. It is likely that it was functioning at the time of the state survey, however. Its closure has affected the biology of the lake in interesting ways.

(See biology below.)

There are, and were at the time of the survey, two inlets into the lake. Water from South Marsh flows into the lake through a small inlet stream except after prolonged periods of drought and during the winter when frozen. East Marsh also connects to the lake during periods of high water.

The lake level fluctuates moderately. At the time of the survey by the state crews (September, 1959) the lake was considered to be 0.5 to 1 foot below normal. That the lake level might fluctuate to as much as 3 feet above that level was conjectured. During the period 1967 to 1969 the lake level fluctuated about 1 foot. Since most of the watershed runoff enters the lake through the marshes the lake level fluctuation is reduced by the restricted flow from the marshes. The water table in East Marsh, for example, has varied over 3 feet from its high point when it flowed into the lake over the rampart to its low point when the water table was 14 inches below the bottom of the dry marsh. South Marsh fluctuates less.

The shoreline of Fish Lake was described by the 1959 survey as being 60% sand with a small amount of scattered gravel, and 40% muck bordered by a swampy shoreline. In part this is still the picture. Now, however, there is no gravel apparent. The most conspicuous feature of the shoreline along the north and east side of the lake is the dikelike rampart formed by shifting ice pushing up a ridge of sand mixed with plant fragments. This varies from 3 to 5 feet in height. Along the north this is bordered into the lake by a band of cattails growing out of firm sand. Throughout the summer the bottom, among these cattails, is hidden by suspended firm jelly balls of blue-green algae and plant fragments. Along the east shore the cattails give way to a variety of emergent aquatics growing out of firm sand.

Along the south to southeast the shore is of sand. At several points the water is eroding the precipitous bank and carrying the sand back into the lake. The southwest shoreline follows a bay and is an area of deposition of organic matter and silt. It is very soft and mucky. The central-west side of the lake is confluent with West Marsh. Being on the sheltered side of the lake in relation to the prevailing winds this too is an area of deposition of all types of silt and organic fragments and is very mucky. The northwest quarter is variously willow- and cattail-bordered and is mucky.

Except for a narrow band along the east, the northeast, and the southeast shores, which are windswept, the bottom of Fish Lake is densely covered by rooted aquatic plants. By June 1 the various pond weeds are so thick over most of the lake that running an outboard motor is impossible (except for the narrow windswept area). This condition persists until mid-September when the plants begin to die and go down.

Fish Lake, its chemical attributes

Chemical analysis by the survey was limited to total alkalinity which was 50.0 ppm (the lake was classed as a moderately hard-water lake), and Dissolved oxygen which was 8.7 ppm at 26.4 C.

In the early phases of this study, dissolved oxygen was taken at each visit to the lake. It repeatedly ran near saturation varying from 6.0 ppm in June to 10.5 ppm just before freezeup. Winter oxygen varied from a high of 6 ppm to a low of substantially 0.0 ppm (Winkler method). (Such a trace that error in taking sample would account for it.) This severe drop was found during January of 1967. During the winter of 1967-68 the oxygen measurements were never below 2.5 ppm.

Winter oxygen depletion is undoubtedly the main limiting factor in the habitat of Fish Lake. (See biological attributes.)

A single chemical analysis of Fish Lake was run on August 12, 1969, as a record for this study by the State Department of Conservation, Division of Fisheries Research (Table 14).

Fish Lake, its biological attributes

Fish Lake supports a rich and varied biota. Only those species with a major effect on the environment, those that occurred regularly in minnow traps, those that occurred in the diet of mudminnows, and those that were conspicuous by their size or special abundance are noted.

Plants Some information on Fish Lake before 1959 was obtained in conversations with residents of the area. They reported that the present weedy condition did not exist; that it was a good fishing lake for northerns, sunfish, and bullheads; and that it was an excellent duck hunting lake with an abundance of wild rice.

The 1959 survey, however, describes the vegetation about as it is today as follows: "At the time of the survey submerged and floating-leaved aquatic plants were abundant throughout 95% of the lake. Emergent aquatic plants (mostly cattail) were abundant along the boggy west and northwest shorelines of the lake. Some of the common species of aquatic plants present in the lake were cattail, bulrush, spikerush, wild rice, yellow water lily, white water lily, water shield, water milfoil, bushy pondweed and various other *Potamogeton* species."

Rooted aquatic plants cover the bottom of Fish Lake (Figure 13).

Table 14. Chemical analysis of Fish Lake taken August 12, 1969. (Tests Run by Minnesota Department of Natural Resources.)

Test	Results (ppm)
SO_4 ion	3.2
Total P	0.028
Soluble P	0.002
Cl ion	0.1
NH_3 N	0.12
NO_2 N	0.002
NO_3 N	0.048
TKN	1.30
Total Alkalinity	40.0

Najas flexilis covers the bottom in water 3 feet deep and deeper. It extends up about 2 feet from the bottom and forms a continuous dense layer. Potamogeton amplifolius grows up through the Najas in many areas of the lake forming dense stands. In mass it is second to Najas and probably covers 30% of the lake bottom. Scattered more widely over the lake but never forming dense masses is Potamogeton praelongus. Potamogeton natans is restricted to an island area along the middle one-third of the south shore near the opening into South Marsh. Potamogeton gramineus is sparsely distributed along the northeast and east shore of the lake then attains its greatest density in the southeast portion of the lake. It is primarily in shallow water 4 to 18 inches in depth. Potamogeton pectinatus and Potamogeton zosteriformis are very sparse and widely scattered in the lake.

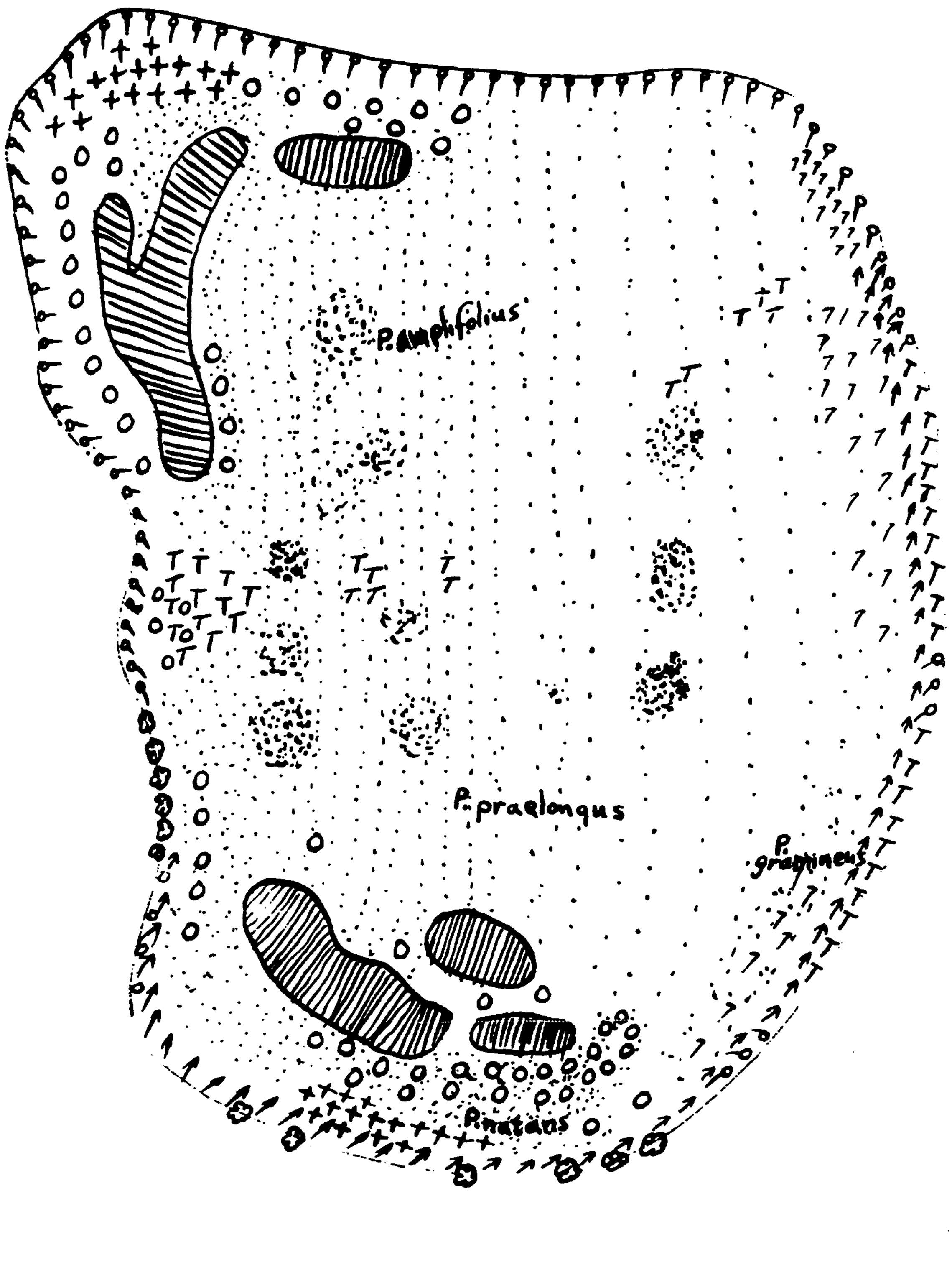
Water milfoil (Myriophyllum sp.) is most abundant in a line about 50 yards out along the south shore. However, it is scattered sparsely over the lake. Chara does not compete with Najas but otherwise is scattered over the bottom. No dense stands of Chara are found.

Among the emergents the cattail (Typha latifolia) is most abundant forming a band 10-20 feet wide along the northwest, north and northeast shores of the lake. Along the middle of the west side the cattails of the West Marsh form the border between the lake and the marsh. Scirpus acutus borders the cattails into the lake in the northeast corner, and then extends southward beyond the cattails along the east shore. It forms two island-areas in the middle of the lake and an extensive band inside the cattails of West Marsh. Two species of Eleocharis occur abundantly. One, a small species about 3 inches tall and growing completely submerged, forms a carpet over the bottom in the shallow water where sand forms a firm bottom in a

Figure 13. Chart of Fish Lake showing the distribution of the major vegetation types. The symbols as placed represent conspicuous concentrations but not the limits of distribution in the lake. 1968.

Legend:

- Arrowhead (*Sagittaria* sp.) . . . .
- Bulrush (*Scirpus acutus*) . . . .
- Cattail (*Typha latifolia*) . . . .
- Overhanging trees, mainly birch (*Betula papyrifera*) . . .
- Pondweeds (*Potamogeton* spp.) . . . .
- Spike Rush (*Eleocharis* sp.) . . . .
- Three-square Rush (*Scirpus americanus*) . . . .
- White Water Lily (*Nymphaea odorata*). . . . .
- Yellow Water Lily (*Nuphar variegatum*). . . . .
- Water Shield (*Brasenia schreberi*). . . . .
- Waterweed (*Anacharis canadensis*) . . . .
- Wild Rice (*Zizania aquatica*) . . . .


P. amphifolius
P. praelongus
P. gramineus
P. natans

foot or less of water. The other is an emergent form and is fairly abundant along the east shore of the lake.

Wild rice (Zizania aquatica) is found in water 3 feet and less in depth in two extensive beds, one along the south shore near the inlet from South Marsh and the other in the northwest corner of the lake. Sagittaria, either as one highly variable species or as two or more species, occurs around the lake in water 6 inches and less in depth and on the shore.

Both the white water lily (Nymphaea tuberosa) and the yellow water lily (Nuphar variegatum) are abundant. They are especially abundant on the southwest, west, and northwest sides of the lake in scattered patches from the shore to about 100 yards out. Water shield (Brasenia schreberi) forms dense islands adjacent to and lakeward from the water lilies.

Fish Great changes in the fish populations have occurred since the 1959 survey. Eleven species of fish were taken in the survey compared to four species in the present study. Only one species is common to both studies. Fish taken in the survey were common sucker (Catostomus commersoni), carp (Cyprinus carpio), brassy minnow (Hybognathus hankinsoni), fathead minnow (Pimephales promelas), black bullhead (Ictalurus melas), brown bullhead (Ictalurus nebulosus), yellow perch (Perca flavescens), Iowa darter (Etheostoma exile), greem simfosj (Lepomis cyanellus), pumpkinseed (Lepomis gibbosus), and bluegill (Lepomis macrochirus). The four species present at the time of this study are the mudminnow (Umbra limi), brook stickleback (Eucalia inconstans), finescale dace (Pfrille neogaea), amd the one species in common, the fathead minnow.

The major alteration in the physical nature of the lake has been the closing of the outlet from Fish Lake to Cedar Creek. This, together with the periodic winterkills has resulted in the selection of fish populations which can tolerate the severe depletion of oxygen in the winter. The survey report noted resident reports of occasional winterkills. As long as the lake was connected to the creek the lake could be repopulated by the fish moving upstream in the spring. Several years without a winterkill would allow populations to become reestablished. It is assumed that the present species were in the lake at the time of the survey. Being of small size, having the habitat preference they appear to be thriving so well in, and possibly being much fewer in numbers in the presence of the several predator species, they could easily have been missed.

The mudminnow shares habitat with the brook stickleback. They are taken together in traps over the lake in the winter, they migrate together in the spring, and can be taken together throughout the summer and fall in the marsh. The young are active within a week of each other, the stickleback being slightly ahead. Many of both species remain in the marsh in the fall not making their way back into the lake. Any competition between the two species was not established. The mudminnow is a predator on the stickleback. Sticklebacks were found in the stomachs of larger mudminnows in both January and April. A possibility exists that on occasion the attempt to swallow a stickleback may result in the death of the mudminnow. Two mudminnows were found dead, each with a stickleback partially swallowed but with the tail protruding from its mouth.

Although the fatheads are frequently taken with the mudminnows in the lake traps their habits are quite different. The fatheads do not leave the lake for the marshes. Spawning is in the lake. A common site for their spawning is under a board or a log which is near or on the bottom.

They hollow out a depression under the object and lay their eggs on the underside. The male stays with the nest and defends it against intruders.

Breeding tubercles were first observed on May 12, 1968. By May 21 the males had fully developed breeding tubercles and were in full color. The males became especially susceptible to trapping and were taken in great numbers. Spawning was first observed on June 3. By July 8 schools of young fatheads were apparent. The last eggs observed were on August 9.

No competitive relationship between the fathead minnow and the mudminnow was established. The mudminnow preyed upon the fathead.

The finescale dace occupied a very limited range in the lake as indicated by the sampling method used. On April 13, 1968, a trap placed in the northwest portion of the lake (designated by 5, April 13, Figure 3) contained 30 dace. This was the first time this species had appeared in the traps. Subsequently, whenever the trap was set in this rather limited area, the species was taken in fairly large numbers. On April 29 both males and females were in full breeding color. The males were brilliant red on the sides; the females were a beautiful yellow-green in a similar pattern. This condition was maintained through May 24 when this trap was removed.

The only feature that made this area notably different from other parts of the lake was the presence of an especially heavy bed of sunken *Potamogeton amplifolius*.

The time and site of spawning were not established. No relationship with the mudminnow was established.

Mollusks Gastropod mollusks are well represented in Fish Lake. They are related to the mudminnow in at least 2 ways: (1) many mudminnows are infected with metacercariae of flukes, (2) the mudminnows feed on the young and smaller snails. The lake is not used for swimming because the cercaria of Schistosoma spp. are present in such numbers as to give very severe dermatitis (swimmer's itch) during much of the summer. The species of snails present characterize the lake. Very abundant in the lake proper is Lymnaea stagnalis which is characteristic of large ponds; Helisoma trivolvis, a pond snail (although it is frequently found in the shallower water of rich and weedy lakes and stream edges); Stagnicola exilis, a temporary pond snail (found here only along the shore of the lake and much more abundant in East Marsh); Bulimnia megasoma, a sedge marsh snail (found along the south edge of Fish Lake but much more abundant in South Marsh); Physa sp., the most tolerant and widespread of snails. Helisoma campanulata and Planorbula sp. are more characteristically limnetic and lend credence to referring to the body of water as a "lake."

Insects No attempt was made to make a detailed analysis of the insects and their life histories. However, several entered regularly into trapping samples and were saved; others were so conspicuous by their abundance that they were observed more closely.

Orders conspicuously present were Odonata, Hemiptera, Coleoptera, Trichoptera, and Diptera. Present in small numbers were Ephemeroptera and Lepidoptera. The Odonata were observed more closely than any other group. The naiads occurred in the minnow traps continuously from the forepart of August until the emergence of imagos in early June. Five species from the lake drew the most attention: the blue darner, Anax junius; a burrowing dragonfly, Gomphus sp.; a climber, Ladona sp.; and 2 species of Sympetrum.

The order Coleoptera was represented by 4 families: Dytiscidae, Gyrinidae, Hydrophilidae, and Chrysomelidae. The dytiscids were taken in minnow traps regularly probably being attracted to the traps by the captive fish inside. Four genera were identified: Hoperius, 1 species; Hydaticus, 2 species; Rhantus, 1 species; and Dytiscus, 2 species.

Hydrophilidae was represented by 3 species: Hydrophilus triangularis and 2 species of Hydrocharus.

Gyrinidae and Chrysomelidae did not occur in the traps. Two species of Gyrinidae and one of Chrysomelidae were abundant but were not identified.

The study of the insects of Fish Lake would make a fascinating study in itself. Time limited carrying it further in this study.

Smaller insects occur in the diet of the mudminnow. It is likely that mudminnows fall prey to the larger predaceous insects although this was not observed.

Plankton A list of plankton organisms is prepared to give an idea of the variety of organisms found there (Table 15). Those listed are classed as common to abundant with some reaching bloom proportions at certain times.

In the month of January, 1969, two stations were established on the north side of Fish Lake. Station I was 100 yards out from shore over 4 feet of water; station II was 200 yards out from shore and over 6 feet of water. Both were over vegetation and aside from depth no differences were notable between the stations. About a foot of snow covered the ice at the beginning of the period and about 4 inches were added during the observation period. The oxygen went down from over 6 ppm to 4 ppm at both stations during the period.

Four objectives were sought: (1) to compare the plankton at the two sites; (2) to note any change in plankton constituents over time; (3) to see the effects of oxygen depletion if the oxygen were to go out as it did in 1968; (4) to correlate the feeding habits of the mudminnow with the food available in the plankton. Data are shown in Table 16.

There were variations between the two stations and from sample to sample at the same station. However, no explanations for the variations were apparent.

Further plankton analysis was set aside for future consideration. No relationship could be established between the mudminnow and the plankton.

West Marsh

West Marsh is predominantly a cattail marsh with some areas of bulrushes and a very limited area of grasses and sedges. Practically none of it is developed as sedge hummocks which are abundant in South Marsh and much used by the spawning mudminnows.

West Marsh opens very widely to the lake, actually being an expanded bay of the lake. Historically, before the closing of the culvert under the road and even before the road, an outlet flowed from the lake through this marsh to Cedar Creek. This marsh attains its greatest depth on the side adjoining the lake where it is about 3 feet deep over a very soft bottom along its cattail border. On its western border it is shallow and expands out widely and contracts greatly as the lake level rises and falls.

It was established that the mudminnows use this marsh to some extent. Mature mudminnows migrate into it in the spring, out of it in the late summer, and young mudminnows can be collected in it in the late summer. No breeding mudminnows were collected during the breeding period in the stands of cattail and bulrushes. They were collected in stands of Carex sp. along the southern margin of the marsh. Although there appeared to be

Table 15. A listing of the organisms identified in plankton from Fish Lake during all seasons, 1968-69.

Cyanophyceae

- <u>Anabaena</u>
- <u>Coelosphaerium</u>

Chlorophyceae

- <u>Pediastrum</u>
- <u>Scenedesmus</u>
- <u>Ulothrix</u>
- <u>Staurastrum</u>
- <u>Cosmarium</u>
- <u>Micrasterias</u>
- <u>Genicularia</u>
- <u>Volvox</u>

Chrysophyceae

- <u>Dinobryon</u>
- <u>Diatoma</u>
- <u>Fragilaria</u>
- <u>Gomphonema</u>
- <u>Pinnularia</u>
- <u>Cymbella</u>
- <u>Tabellaria</u>

Protozoa

- <u>Difflugia</u>
- <u>Peridinium</u>
- <u>Didinium</u>

Rotifera

- <u>Filinia</u>
- <u>Polyarthra</u>
- <u>Notholca</u>
- <u>Keratella</u>

Crustacea

- <u>Cyclops</u>
- <u>Diaptomus</u>
- <u>Ceriodaphnia</u>
- <u>Chydorus</u>

Table 16. Mean number of plankton organisms per ml of sample from two stations on January 14 and January 21, 1969. Station I was in 4 feet of water and station II was in 6 feet of water. Ten liters of lake water were concentrated into the 100 ml sample.

	Station I		Station II	
Organism	Jan. 14	Jan. 21	Jan. 14	Jan. 21
Cyclops	4	1	2	4
Diaptomus	1	2	18	34
Chydorus	12	12	0	2
Polyarthra	167	259	38	21
Keratella	79	73	24	27
Difflugia	0	7	0	0
Peridinium	347	251	101	83
Dinobryon	8	92	18	313
Cymbella	1	6	1	2
Fragilaria	0	8	1	0
Tabellaria	0	4	0	0
Gomphonema	0	2	0	0
Scenedesmus	0	0	8	0

little reproduction in this marsh compared to South Marsh in 1968 it would be the major source of recruitment during dry years when both East and South Marshes would be disconnected from the lake.

East Marsh

East Marsh is very different from West Marsh. Due to the ice-formed rampart and raised shoreline (previously described) this marsh is isolated from the lake except in periods of unusually high water. In addition the water level drops rapidly when the source of water (rain or snow water) is lost. The rate of loss slows as the water level attains 6-8 inches but it still goes down much faster than South Marsh or the lake proper. The shallower water promotes the growth of grasses and sedges with only sparse and scattered cattails. In the years of sufficient snow to give a good runoff at the time of the spring breeding run, a large population of young mudminnows is produced here. This was the condition in the spring of 1967. During the summer and fall there was very little rain and the marsh dried up completely. The water table dropped to about 10 inches below the dry bottom of the channel in the marsh (14 inches below the sedge marsh bottom). This was the condition of the marsh when it froze in 1967. Thus this marsh contributed nothing to the recruitment of mudminnows in Fish Lake in that year. (See survival under adverse conditions, drought and freezing.)

In 1968 East Marsh again failed to serve as a source of recruitment. Very little snow in the winter of 1967-68 and very little rain in the spring resulted in no contact being established between the marsh and the lake during the spring breeding season. Rain in June allowed a midsummer movement of fish into the marsh but there was no spawning there in 1968.

South Marsh

South Marsh presents the most suitable conditions for the mudminnow and the most favorable conditions for observation and study. Its connection with the lake has undergone modification. Initially it apparently entered through a narrow channel eroded through the otherwise raised shoreline separating the lake and the marsh. In the late 1940's a channel was dug in an attempt to drain the marsh. When the area became a part of the Natural History Area a dike was built across the channel to reestablish the marsh. At present, seeps have developed through the sidewalls of the dike which form a small flowage, about 2 feet wide, to the lake. During the time of this study the flowage has been as much as 4 inches deep; it was dry, due to low water, for only about 2 weeks in the late fall of 1967. In August of 1967 the water in the channel was so shallow that young-of-the-year mudminnows frequently became stranded on the little sand islands that formed between the rivulets. They would lie there on their sides as if resting for a few minutes then flip about until they landed in the shallow rivulet where they would orient themselves and swim downstream toward the lake.

South Marsh has aspects of a bog as well as a marsh. In from the north margin, where most observations were made, the vegetation goes from grasses, to sedges, to sedge hummocks, to a floating sedge bog. In between the hummocks and among the bog sedges is a tangled complex of plant fragments, dead and living sedges, bladderworts, water buttercups, filamentous algae, other algae and diatoms. In between the hummocks, and below them, the waterways widen out so that there are overhanging roofs of filamentous roots forming entangled masses with the above-mentioned material interspersed.

South Marsh has exceptional ability to hold water maintaining a level above that of the lake at all times. While East Marsh is dropping 2 feet South Marsh, even with constant flow, will drop about 8 inches. The geological structure of the area makes the presence of substantial springs unlikely. A more effective bottom seal especially along the lake side of the marsh seems to be the best explanation at present.

The temperature of the water in the flowage from South Marsh is generally below that of the lake even though the top 1-2 inches of the marsh may be as much as 2 C above that of the lake. Following heavy rains and during cooling periods the lake and the inlet temperature come together and may become the same. In rising temperatures the lake warms more rapidly than the marsh but the spread between the inlet and lake was never more than 4.5 C and most frequently was about 2 C.

DISCUSSION

Fish Lake and the marshes attached to it provide a variety of habitats and conditions suitable to sustain a vigorous population of mudminnows. The marshes provide breeding habitat for the adult mudminnows and food and cover for the developing young; the luxurious bottom vegetation over most of the lake provides cover for the mudminnows and provides extensive surface to support the growth of organisms which are used as food by the mudminnows; species of fish which would be predators on the mudminnows are not present because of the occasional loss of oxygen under the ice in the lake in winter and because the lake is isolated from Cedar Creek which is the only potential natural source for recruitment of predator species.

The migration patterns of the mudminnows were well documented in the course of this study. During the winter the fish are distributed widely over the lake being taken in all test traps except those along the shallow margin adjacent to West Marsh. (Mudminnows placed in holding cages in this water died within 24 hours. The lethal agent was not determined but that it was other than oxygen deficiency seems assured since survival in other parts of the lake was high even when the oxygen level dropped to substantially zero.) The mudminnows move toward the shore of the lake with or soon after the breakup of the ice. The breeders then move to mouths of the channels connecting to the marshes. Following a brief period during which there is a considerable buildup in numbers, the mudminnows move up the channels and into the marshes.

I am not able to say with certainty that spawning took place in the lake. My attention and trapping effort were directed toward following the migration. However, mudminnows were taken in traps along the north and northwest shore of the lake throughout the period of breeding in the marsh. Young-of-the year began to be taken in the lake traps at about the same time they began to run into the lake from South Marsh and they were readily available in the lake for the colonizing of East Marsh when it became attached to the lake. However, I cannot say for certain that the young-of-the-year had not come into the lake from the marshes.

Spring migration of breeding adults takes place very early and while the water is very cold. The temperature of the water flowing from South Marsh was 9 C on the day of the peak migration. The mass migration of the breeders from the lake to the marsh is accomplished in a short time. Six days, April 9 to April 14 inclusive, accounted for the major movement.

Spawning is delayed for some time after the fish arrive in the marsh. The first partially spent female was taken on May 21. Once begun, spawning proceeds rapidly. By May 26 several females taken were partially to wholely spent; May 29, June 3 and June 4 all females captured were spent. The last female to be taken, still carrying a few eggs, was on June 6.

Spawning takes place while the water temperature is still low. Ice was still present in the bottom of the marsh and the temperature of the water 4 inches above the bottom was 10 C on June 4 when spawning was substantially completed. The temperature in this deeper water between the hummocks where spawning is believed to have taken place was fairly constant at about 10 C during the spawning period.

The first young-of-the-year (2 fry, 7 mm long) were dipped from South Marsh on June 11.

Within about 40 days from the appearance of the first fry, the young-of-the-year begin to leave the marsh and go into the lake. These fish possess a strong positive rheotaxis. They make their way through the outlet of the marsh into the lake orienting continuously on the most rapid part of the flow. A trap, placed in the flowage, which inhibits the flow of water is bypassed fluidly as the small mudminnows slip along in the deflected flow. The flow through the many acres of marsh must be nearly imperceptible yet the tiny fish make their way to the small outlet into the lake. I propose that it is this "flow" which guides them to the outlet, but it would be very difficult to test this hypothesis.

In spite of the massive migration of spent breeding adults and later young-of-the-year from the marsh into the lake, many of each remain in the marsh for the winter to survive or perish depending on the conditions presented. Traps in South Marsh continued to capture mudminnows right up to ice formation.

The mudminnow is tolerant of some seemingly adverse conditions in its environment but limited by others. Oxygen deficiency in warm water, freezing, and drying and freezing of its habitat have been shown to be lethal to it. Its hardiness is apparent in its ability to breathe atmospheric oxygen at the surface; in its ability to follow the water table down among the roots and peat of sedge marshes; in its ability to survive oxygen depletion, lethal to most other vertebrates, in the winter under the ice; and in its ability to make its way from one habitat to another with a small amount of water in which to move. Especially favorable to its survival in the marshes is the fact that the ice line here will generally be quite shallow. The insulation afforded by the snow, ice itself, and vegetation of the marsh kept the frost line to as shallow as 11 inches while the depth of ice on the lake was as deep as 24 inches in 1968. Survival in the marsh was not positively established, however.

Although it is difficult to be sure that similar groups (in age, size, and sex) are being compared it appears that the mudminnows in Fish Lake produce a greater number of eggs and attain greater ultimate size than those described in the literature from Michigan, Indiana, and New York.

It appears that the mudminnow is capable of utilizing either or both plants and animals in its diet. In some habitats it apparently feeds primarily on vegetable matter while in others it feeds almost entirely on animal matter. In Fish Lake it feeds on both plants and animals. Except for the fish, one characteristic of the food items is that they are attached or crawling forms, frequently found on plant surfaces, showing a grazing habit. Plankton does not enter into the feeding pattern. For example: *Diaptomus* and *Cyclops* occurred in plankton with high frequency but did not appear in the stomachs while *Canthocamptus* was frequent in the stomachs but did not appear in the plankton; ostracods appeared in the stomachs but only one occurred in the plankton samples examined; *Spirogyra* appeared in stomachs but did appear in the plankton samples; the blue-green algae *Gloeotrichia* was a common food item and did not appear in the plankton; planktonic blue-green algae were not identified in stomach samples.

The mudminnow serves as the primary host for several parasites and as the intermediate host for many more. There is no apparent relationship between the growth rate and the number of metacercariae carried in the 2- and 3-year-old mudminnows. A complete survey of the parasites of the mudminnow in Fish Lake is of such a magnitude as to warrant a separate study.

Otoliths provide a dependable means for aging the mudminnow

Alternating opaque and clear rings are laid down in a manner which makes it possible to determine the age by counting the dense (opaque) rings. Scales show no distinguishable seasonal differential growth. No annuli are formed. The number of eggs per female shows a direct relationship with the size of the fish and is not a function of the age, except as the older fish tend to be larger. Where two fish of the same size are of different ages there may actually be a tendency for the younger fish to produce more eggs but the incidence of the size overlap is so low in the data of this study that reference to the possibility is only conjecture.

The length of the mudminnow decreases as a result of preservation in 4% formalin. Larger mudminnows lose a greater percentage of their live length than do smaller ones. The weight of the mudminnow increases in preservation. It is very difficult to standardize weighing procedures. The greatest difficulty lies in establishing a method by which excess water can be removed uniformly from one fish to the next or from one weighing to the next. Results are so highly variable that it is doubtful that the data are reliable. Multiple handling, washing specimens in water (to facilitate handling), allowing the specimens to lie in air for even brief periods, and adding solution to storage containers to replace evaporated liquid all affect the weight. In weighing such small fish the small variations in technique give high percentage errors in data.

Fish Lake does not lend itself readily to categorization. In terms of kinds of fish, as we have lake trout lakes, sunfish lakes, walleye lakes and bullhead lakes, it would appropriately be classed as a "mudminnow lake", or a "fathead minnow pond". From the standpoint of invertebrate fauna present, especially the snails which tend to characterize habitats quite well, it would be as much a pond as a lake. It supports a good limmetic plankton with species characteristic of eutrophic lakes. The presence of several desmids notably Staurastrum, Cosmarium, Micrasterias, and Genicularia is reminiscent of the soft-water acid ponds of the Itasca Park (Clearwater Co., Minnesota) area. The low levels of nitrates and phosphates attest to its freedom from pollution. The productivity is evidenced by the complete coverage of the bottom by aquatic plants.

The occasional depletion of the oxygen supply under the ice together with the isolation of the lake from Cedar Creek (which precludes access by additional species of migrating fish) are the principal limiting factors conspicuously apparent. The species present are those that can tolerate the low oxygen level for a prolonged period during the winter.

Continued work on the mudminnow and on Fish Lake is proposed. The exact breeding sites, breeding behavior and egg deposition were not observed. The possibility of installing underwater television was examined but could not be developed at the time of this study. No idea of the total number of mudminnows involved in the mass migrations is developed in this study. Survival of the mudminnow in the marsh was not established or refuted. Holding cages with positive bottom seals to insure the mudminnows remaining in the cages throughout the winter should be producible.

Thinking in terms of Fish Lake itself each of the other species of fish presents a challenge similar to the mudminnow. A detailed life history of the dragonflies, either of Gomphus sp. or Ladona sp. which are so abundant or any of several other species present warrant study. Detailed plankton studies will yield very interesting cycles. In early fall there is a plankton depletion to the point of near elimination. The factors involved in this depletion need examination.

A most interesting study would be an analysis of the aufwuchs of Fish Lake. The study of organisms using artificial surfaces placed horizontally and vertically and at various depths from the bottom to the surface as well as emerging from the water would be most interesting. Traps and floats were used extensively as sites for egg-laying, growth, and emergence by various categories of animals but a detailed analysis was not pursued.

An analysis of the life of the marshes with productivity and life history studies offers opportunity for study.

I hope to involve many students in followup studies suggested by the present study.

SUMMARY

1. During the periods August 4 to November 8, 1967; January, 1968; March 31 to September 15, 1968; January, 1969; February and March, 1971; and July and August, 1971; field data pertaining to the mudminnow in Fish Lake were gathered.
2. Approximately 3600 trap days were used in gathering field data and over 3036 mudminnows were examined for one or more items of information.
3. Minnow traps and dip nets were used to sample the population.
4. In January, 1968, the mudminnows were distributed widely over the lake. Only the west border of the lake, adjacent to West Marsh, did not support a mudminnow population. Here the water was actually toxic, being lethal within 24 hours to fish placed there in holding cages.
5. With the melting of the ice, about April 1, 1968, the mature mudminnows (age II and over) migrated toward the shore, and then peripherally around the lake and out into the marshes where they spawned.
6. Spawning completed, a mass migration of spent breeders back into the lake took place between June 20 and July 12, 1968. The migration continued at a reduced rate until the marsh and channel froze.
7. The young-of-the-year began moving into the lake from the marshes in mid-July. The migration reached a peak the last week in July but continued at a reduced rate until the marsh and channel froze.
8. Colonization of a habitat which became available due to high water in late July, 1968, was accomplished by age I and age 0 mudminnows. Age I fish were predominant.
9. Mudminnows matured at age II in Fish Lake.

10. Breeding took place during the last week in May and the first week in June in 1968.
11. The number of eggs per female was found to be greater in the Fish Lake population than in other populations reported in the literature. The least eggs per fish was 216 in a 66 mm, age II, female; the most, 3828 in a 134 mm, age III, female.
12. Females attain larger size than males in age II, III, and IV in Fish Lake.
13. The mudminnow in Fish Lake attains larger adult size than in other populations reported in the literature. The greatest length measured in this study was a female 156 mm long (TL).
14. Preservation in 4% formalin reduced the length in the mudminnow by an average of 3.36%. A greater percentage of length was lost in larger fish.
15. Preservation increased the weight of the mudminnow. Data regarding weight, however, were considered to be doubtful validity because of the great variation in the values attained. The error is associated with the removal of "excess water" in weighing, and with other variables in handling and storing the specimens.
16. The otoliths provided a reliable means for age determination in the mudminnow.
17. Scales, length frequency and number of eggs were unsatisfactory as age indicators.
18. The temperature of the water during the spawning migration was 9 C.
19. The temperature at the site of probable spawning and egg development was 10 C. (Ice was present in the bottom of the marsh only a few

inches below the developing eggs and did not disappear completely until June 18, 1968.)

20. Temperature (changing temperature?) appears to influence migration rate in young-of-the-year fish, with lower temperature stimulating movement and higher temperature inhibiting movement.
21. The mudminnow in Fish Lake was found to be active and feeding in the winter under the ice at 0-2 C.
22. The combination of drying of the habitat and the resulting deep frost line in East Marsh was lethal to the mudminnow in the winter of 1967-68.
23. The mudminnow tolerated oxygen depletion to substantially 0 ppm under the ice during January, February and March, 1967.
24. The mudminnow survived drought conditions in East Marsh by following the water table, making its way down among the fibrous roots of the marsh vegetation.
25. The mudminnow survived low oxygen conditions in containers of "warm" water by coming to the surface and breathing air.
26. In migration the mudminnow demonstrated its ability to make its way from one habitat to another in a minimum amount of water.
27. The mudminnow was found to be infected with adult and immature stages of parasites.
28. No relationship was found between size or age and the number of metacercariae in the skin. The number of metacercariae varied from 0 to 494 per fish.
29. The food of the mudminnow consisted of plants and animals that were found growing on leaves and stems of aquatic plants showing a pattern of feeding by grazing over the surfaces.

30. Plankton was not a constituent of the diet.

31. Mudminnows fed on the brook stickleback and fathead minnow.

32. Fish Lake and its associated marshes were found to support a highly varied flora with which the mudminnow identified closely for cover, breeding, and grazing for food.

33. An abundant and varied fauna was found to be present in Fish Lake and its associated marshes.

34. Chemical analysis showed the water of Fish Lake to be of high quality, of moderate hardness and to have a moderate level of SO_4, P, N and Cl.

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ACKNOWLEDGMENTS

This project has touched the lives of many people to all of whom I am grateful. The graduate faculty in the Department of Zoology and Entomology encouraged me to undertake the PhD. program. The members of my thesis committee, Dr. Tauber, Dr. Carlander, Dr. Laffoon, Dr. Bachmann, and Dr. Landers (Botany Department), were especially encouraging. The labors and helpful suggestions of Dr. Bachmann, my advisor, and Dr. Carlander were essential to the development of the research project and writing the thesis. I am especially grateful to Dr. Laffoon for his meticulous care in reading and correcting the mechanics of this paper.

I am indebted to the Minnesota Academy of Science and the University of Minnesota and especially the staff associated with the Cedar Creek Natural History Area for their cooperation in making the facilities of Fish Lake and the laboratory available to me.

To the many Macalester College students who may have been inconvenienced by, and the many who were involved in, the research I express my appreciation.

And to my wife, Shirley, and my five daughters whose labors, sacrifices, and strength of character enabled me to pursue this endeavor must go a very special thanks.